Forest Entomology in East Africa

Forest Insects of Tanzania

Hans G. Schabel

Springer

FOREST ENTOMOLOGY IN EAST AFRICA: FOREST INSECTS OF TANZANIA

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Springer

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DEDICATION

To the people of Tanzania, whose kindness and cultural diversity are only matched by the natural wonders of their beautiful country. Safari njema!

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PREFACE

In January 1983, while under contract with the Norwegian International Development Agency (NORAD), I started teaching Forest Entomology among other subject areas at Sokoine University of Agriculture (at that time still a branch of the University of Dar es Salaam) in Morogoro, Tanzania. The task of delving into the tropical dimensions of forest biology and life in a different culture proved both challenging and exhilarating. The wealth of insects was amazing, yet despite access to the University's general library and a small collection of more specialized literature available at the Faculty of Forestry, no reference collection of insect specimens, no backup from other forest entomologists, no internet, and, importantly, not a single book dealing with the forest insects of Tanzania (or any part of Africa, for that matter) existed. The East African Agricultural and Forestry Journal and a very basic field handbook of Malawi forest insects by Esbjerg (1976) provided the only relief in my efforts to acquaint myself with the most important pest insects of this ecologically diverse region. Even today, in the wake of the rapidly expanding Information Age, an "enormous body of information is theoretically available, but it is highly dispersed, extraordinarily varied in form, uncoordinated, and largely unavailable in most of Africa" (Miller et al. 2000). In the 1980s, without the benefit of the internet for rapid dissemination of information, conditions for research entomologists at African universities were even significantly more trying (Kumar 1987; Klopper et al. 2002).

Spurred on by these challenges, I embarked on a three-year personal mission to collect and assimilate as much information as possible through firsthand observation and field research, photographic documentation while on safari, interviews with old-timers, extensive searches of the German colonial era records at the National Archives in Dar es Salaam and persistent probing for written records in obscure journals, proceedings and dusty government offices, that ultimately resulted in a growing stock of documents and knowledge. I have returned to Tanzania six times in the intervening years, assembling in the process a comprehensive collection of German and English literature relevant to forest entomology in Tanzania, complemented by some French works on African entomology. As reflected in this book's extensive bibliography, Moffett's 1958 claim that "literature on insects of Tanganyika is sparse" was a serious understatement. This book is the culmination of more than 20 years of on-and-off research into the history of forest insects in Tanzania, in the process becoming my personal Kilimanjaro. In both the German and

British colonial periods there had been plans to write such a book, but unstable times and lack of a budget, respectively, had apparently not allowed this to happen.

For the purposes of this book, the term “East Africa” encompasses Uganda, Kenya, as well as Tanzania. While the principal focus is on the forest insects of Tanzania, its two neighbors to the North are strongly linked to Tanzania historically, culturally and ecologically and thus should also benefit from access to this book. Furthermore, since other countries in eastern, southern and central Africa share many species of insects with East Africa and provided relevant literature, this book should also be of use there.

The term “forest insects” as used in this book primarily refers to tree pest species affecting natural forests and woodlands, indigenous and exotic tree plantations, as well as tree nurseries. Insects attacking wood at any stage, i.e., standing (living and dead), down (recently felled or dead logs), in storage or in use, have also traditionally been considered forest insects and thus are covered to at least some degree. The most important predaceous and parasitic arthropods, which play important roles in the natural or biological control of forest pests, are also included.

In recognition of the increasing importance of trees in social and environmental contexts, insects associated with ornamental trees and rural development forests as pests, pest antagonists, or useful insects with the potential for income, have also been considered. It is increasingly difficult to determine where tropical agriculture stops and forestry begins, but agroforestry clearly provides a hybrid model. This land use practice emphasizes multipurpose trees that provide timber and non-timber products, while simultaneously serving for soil conservation, fertilization, fencing, shade and beauty. While many woody legumes in particular meet multiple expectations, they can at the same time be magnets for a plethora of pests. Also, as natural forests become depleted, tree crops that traditionally have been grown for fruit or specialty products are increasingly looked at as substitutes for timber trees in different parts of the tropics. For instance, in Asia furniture is often built with wood from rubber trees, or trees such as mango, tamarind and jackfruit. One eighth of timber in the Philippines already derives from coconut, and a significant share of Asia’s particleboard and fiberboard comes from tree crops, bamboo and agricultural fibers. As a result of these trends, as well as for historic reasons, insects such as coconut rhinoceros beetles (*Oryctes* spp.) are included among the forest pests.

This book consists of three main parts: (1) two introductory chapters describing the natural history of Tanzania (2) six chapters detailing specific pest insects and their antagonists, and (3) one chapter focusing on forest insect industries. Chapters 1 and 2 provide background on Tanzania’s physical environment, as well as its flora and forests. Chapters 3-8 are arranged by feeding guilds, i.e., defoliators; sap feeders; bark, shoot and wood borers; termites and ants; flower, fruit and seed feeders; and finally root and root collar feeders. As the important gall insects in Tanzania are mostly Hemiptera, they were placed into the chapter on sap feeders. To pool ants and

termites in one chapter may be a somewhat unconventional arrangement, but these two unrelated groups share numerous similarities and interact in multiple ways, as explained in the introduction to that chapter. The species profiles reflect those insects that have either caused the biggest and/or most persistent problems in tree culture in Tanzania, are the best known based on research in this country or elsewhere, are common, conspicuous, charismatic, unique, rare or of historic interest. Their selection was frequently based on subjective judgments. Some potentially troublesome invaders, such as the eucalyptus borers (*Phoracantha* spp.) and the newly described blue gum chalcid (*Leptocybe invasa* Fish & LaS.), insects that are already entrenched in other parts of Africa and have been approaching Tanzania, are briefly introduced. In the case of insects that do occur in Tanzania, but for which local data on bionomics may be scant or do not exist, literature from as far as South and West Africa, Asia, the Pacific and even the Americas was exploited, despite the potential for significant regional differences in bionomics. Common insect names listed are mostly based on Crowe (1967).

A broad, general overview of each family or order precedes most categories of insects. Individual generic or species profiles typically provide details on occurrence and damage, describe different developmental stages, outline life history and synopsize historically important or contemporary management practices. Material presented for each insect species or genus reflects the extent of existing knowledge and level of interest. For insects of more marginal interest, only the bare essentials are covered. Many forest insects, for which only host records are available, have been ignored. Coverage of groups of insects or hosts is presented alphabetically.

Chapter 9 considers forest-based insects that have income potential for local people and thus may provide incentives for the retention or restoration of functional forests. This includes segments on edible insects, bee products, wild silk and collectibles. Reference to certain insects in multiple chapters was inevitable. For instance, the emperor moths (Saturniidae) are folivore tree pests and thus are first covered among defoliators. At the same time they are edible, some are silk producers and most are collectibles, for which reason relevant aspects were also dealt with in other appropriate contexts.

In recent years the taxonomy of arthropods has been debated intensely with little apparent resolution among the experts. As a result, this book largely follows the traditional classificational system, incorporating some of the more recent revisions. The presence of numerous synonyms for certain species and other taxonomic levels posed a recurrent challenge during the preparation of this book. Every effort was made to meet current entomological standards. Nevertheless, persistent disagreement on terminology even among specialists guarantees that segments of this book will fall afoul of bewildering taxonomic complexities and inconsistencies. Authority citations for species names are provided where available, but are missing for others for lack of definitive references.

It is my hope that this book will allow future entomological researchers and aficionados in Tanzania and East Africa to hit the ground running, without wasting time on wild goose chases for references or information hidden in foreign language sources and obscure archives. It is also for their benefit that locations and dates for some of the insects pictured are included in the legends. The lack of information on certain species and groups indicates gaps in our knowledge and should help pinpoint opportunities for future work. In addition to professional and amateur entomologists, this book will be useful to forestry and entomology students, resource management field personnel and development workers in Tanzania, as well as its close-by neighbors in southern, central and eastern Africa. Biologists, naturalists, ecotourists and safari operators will also find surprising facts and insights into the natural history of the myriad unique and beautiful insects that make their home in East Africa. For those willing to invest effort to observe the smaller creatures, all of Tanzania is an entomological Serengeti, an exciting world of unparalleled natural wonders.

The author would be most grateful for identification of errors and omissions, as well as granting of copyright for any images that may help improve future editions of this first attempt to comprehensively cover the forest insects of Tanzania.

Hans G. Schabel
Custer, Wisconsin
December 2005

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The large number of insect species dealt with in this first book on the forest insects of East Africa, and especially the complexities of their taxonomy, made it essential to seek the help of numerous individuals with specific talents or expertise. While depending on their input, I greatly expanded my own understanding of the rich insect fauna of Tanzania and neighboring countries. I am most grateful to the following who generously gave their time and expertise in clarifying synonymies, providing specific details, new information or illustrations, and checking various chapters or sections thereof for potential errors or omissions. Any mistakes and imperfections still in place are either attributable to incomplete and unreliable written sources, and/or to my own fallability and follies.

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I am also appreciative of the publishers/photographers/artists named in figure captions for their kind permission to reproduce various illustrations. There are, however, instances where we have been unable to trace or contact the copyright holder, or to receive a timely response. If notified, the publisher will be pleased to rectify any errors or omissions at the earliest opportunity.

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Hans G. Schabel
Custer, Wisconsin, USA
December 2005

FOREWORD

It is with great pleasure that I write the foreword to this book. Although I am presently serving in a political position, I was previously involved with forestry for 30 years, first as a practicing forester, then as a professor and administrator, and finally as a full-time researcher.

Tanzania is known worldwide for its outstanding landscapes and natural wonders. Our physical environment is, however, challenging, and we are facing unprecedented pressures on natural resources. Most of our 37 million citizens rely directly or indirectly on these resources for subsistence or income. Our forests need to satisfy many demands. They provide wood energy as fuel wood and charcoal, building materials, and numerous non-wood forest products. They are also the sources of rivers that provide us with the water we drink, that produce nearly all the electricity we use, and that provide for our irrigation schemes and valuable fresh water fish. In meeting after meeting with my constituents, the central role of natural resources in their lives is evident.

The size of some of Tanzania's natural forests has been reduced by 50% during the last 30 years alone, and plantations continue to be plagued by exotic invaders that seriously complicate their management. As a result, we need to be highly vigilant with respect to any future threats on these limited and crucial resources, including threats from tree insects and diseases.

Insects not only cause notorious health problems in humans and livestock, they also significantly interfere with the production and storage of various crops. In forestry they reduce growth and yield and cause the mortality of trees of all ages. They degrade wood and compromise the soundness of houses and other wooden structures, resulting in significant economic losses. It should, however, not be overlooked that many insects provide important ecosystem services and numerous other benefits. Tanzania is blessed with extraordinary biodiversity and, with its high degree of endemism, is one of two "especially rich" areas in tropical Africa.

While certain groups of organisms, such as flora and various birds, reptiles, amphibians and mammals of Tanzania, have been reasonably well researched and documented, this is not generally true for most groups of insects and some of their invertebrate relatives. Their small size, the sheer numbers of species, as well as the mobility and secretive or ephemeral nature of many insects, has certainly been an impediment to their evaluation. This is clearly reflected in the fact that at this time

only one book has been written that comprehensively deals with a particular group of insects in Tanzania, i.e., Kielland's "Butterflies of Tanzania". While there may be professional papers on insects of East Africa, some dating back to the German and British colonial periods, most of these are hard to find and some require translation. In addition, mimeographed reports issued by various governmental research stations, are difficult to access, if termites have not already destroyed them.

This is the first book dealing with forest entomology in Tanzania, or East Africa for that matter. The value of this book has been greatly enhanced by not focusing exclusively on forest pest problems. It also explores potential exotic tree pests, parasites and predators of pests, as well as beneficial insects, such as those used for food, or to create income. This broader approach aligns with recent shifts in Tanzanian forest policy that identify sustainable land use, the development of Tanzania's land resources and poverty eradication as the overriding goals for future forest management. This emphasis acknowledges conservation values, land protection for hydrological and climate reasons, and envisions afforestation and reforestation for commercial timber and the production of fuel wood, charcoal and non-wood forest products.

Professor Schabel recognized the need for this book more than 20 years ago, when we were colleagues at Sokoine University of Agriculture in Morogoro, Tanzania. At the time he faced having to teach forest entomology without the benefit of a readily available and comprehensive resource. During the intervening years he has been able to unearth, salvage and pull together relevant literature, which, combined with his own research and observations made on numerous safaris provides the basis for this book. This richly and attractively illustrated text bridges a glaring gap. It will make it eminently easier for students, teachers, resource professionals, future researchers and the general public interested in insects of Tanzania to exploit what may be a near complete collection of references and to access this surprising wealth of information.

Dr. J.A. Maghembe
Minister of Labor, Employment and Youth Development
Dar es Salaam
Tanzania

COLOR SECTION

Plate 1.

Plate 2.

Plate 3.

Plate 1. *Podocarpus falcatus*, a major component in the upper reaches of cloud forest. Umbwe, Kilimanjaro
Plate 2. Veteran of *Juniperus procera* on a fairly dry site in montane forest. Mt. Meru Crater
Plate 3. Grove of old specimens of *Nuxia congesta*, a component of dry, montane evergreen forest. Nanokanoka, Ngorongoro Highlands

Plate 4.

Plate 4. Miombo woodland, a fire climax dominated by *Brachystegia microphylla, B. boehmii* and *Julbernardia globiflora,* during leaf flush. Mid November, dry North slope of Nguru ya Ndege Forest Reserve, Morogoro

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Plate 6.

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Plate 7.

Plate 8.

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Plate 9.

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Plate 10.

Plate 10. A well-structured Chagga home garden, showing intense mix of woody and non-woody crops, making it a refuge for generalist forest species and endemic invertebrates. Mweka, Kilimanjaro

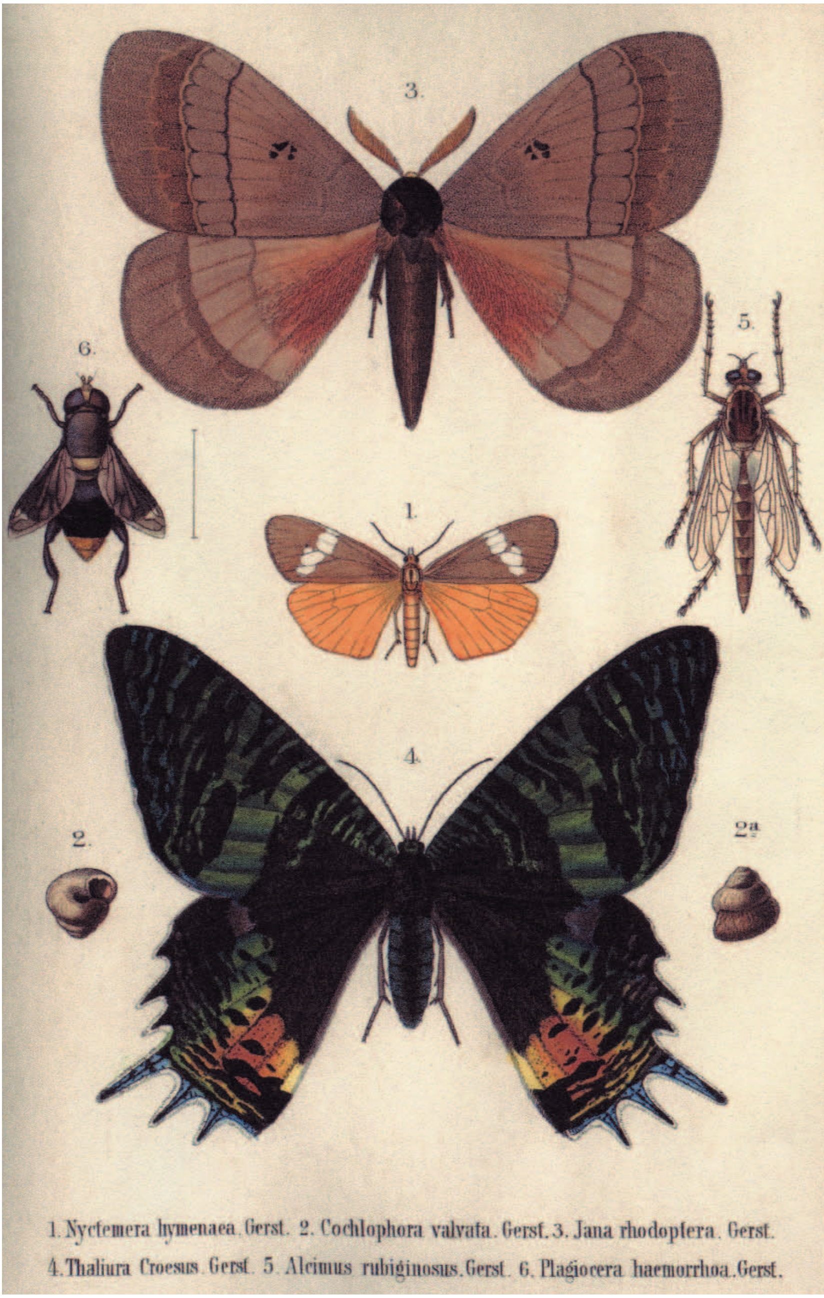

Plate 11.

Plate 11. Copy of hand-painted illustrations depicting various insects collected by Baron C.C. v.d. Decken and O. Kersten during expeditions through Maasailand and at Kilimanjaro, and by C. Cooke in Zanzibar in the 1860s. (From Gerstaecker 1873)

Plate 12.

Plate 13.

Plate 12. A roost of *Papilio demodocus* (Papilionidae). Morogoro
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Plate 14.

Plate 15. **Plate 16.**

Plate 14. An emperor moth (Saturniidae), displaying deterrent eyespots
Plate 15. Advanced instars of *Bunaea alcinoe* (Saturniidae) on *Balanites aegyptiaca*, one of many hosts. Early January, Karatu
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Plate 17.

Plate 18.

Plate 17. A typical but chilled hawk moth (Sphingidae) clinging to life at slightly less than 5,000 m at West Kilimanjaro

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Plate 19.

Plate 20.

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Plate 22.

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Plate 23.

Plate 23. Nymphs and adults of the moth bug *Ityraes gregorii?* (Flatidae) feeding on a milk-weed vine. An assemblage of adults around a branch resembles a colorful leguminous inflo-rescence. Unfortunately, many of the individuals escaped in an explosion of color when the photographer approached

Plate 24.

Plate 25.

Plate 24. *Cupressus lusitanica* (right) showing branch necrosis as a result of attack by giant cypress aphids *Cinara cupressivora* (Aphididae). Dieback typically spreads from the inner crown outward. December, Rongai, Kilimanjaro
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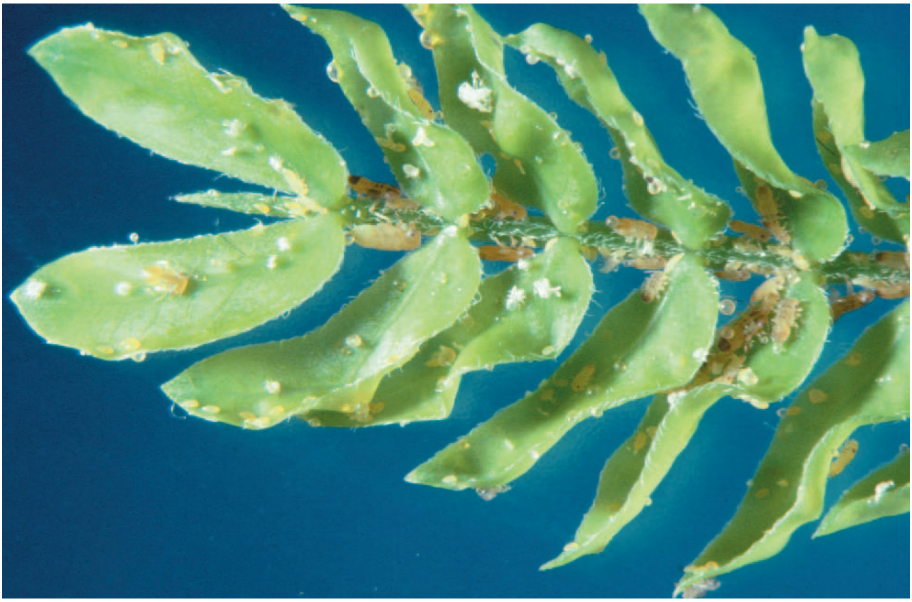

Plate 26.

Plate 27.

Plate 28.

Plate 26. Nymphs of various instars of the leucaena psyllid *Heteropsylla cubana* (Psyllidae) on leaflets of *Leucaena leucocephala*, showing typical distortions of host tissues.
Photographs for Plates 26-30 originating in Oahu, Hawaii. (Reproduced by permission of W. Nagamine)
Plate 27. Severely stunted terminal growth on succulent shoots of *Leucaena leucocephala* as a result of sucking by the leucaena psyllid *Heteropsylla cubana* (Psyllidae)
Plate 28. Near complete defoliation of a patch of young *Leucaena leucocephala* by *Heteropsylla cubana* (Psyllidae)

Plate 29.

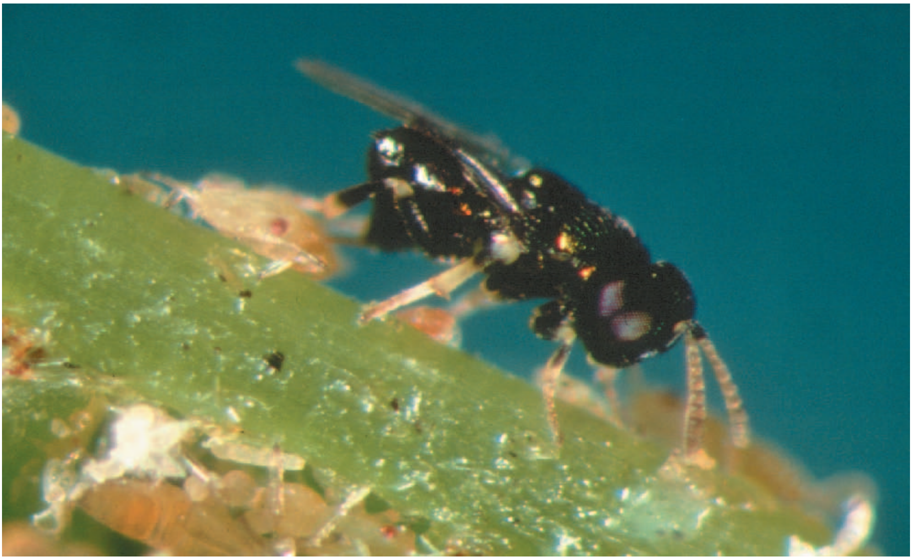

Plate 30.

Plate 29. Larva (left) and adult of the predaceous ladybird beetle *Curinus coeruleus* (Coccinellidae) amidst eggs and early instar nymphs of the leucaena psyllid *Heteropsylla cubana* (Psyllidae)

Plate 30. A parasitic wasp, *Psyllaephagus yaseeni* (Encyrtidae) while laying an egg into a nymph of *Heteropsylla cubana* (Psyllidae)

Plate 31.

Plate 32.

Plate 33.

Plate 31. Carving made of African blackwood *(Dalbergia melanoxylon),* with sapwood honeycombed by presumably round-headed wood borers (Cerambycidae). Karatu
Plate 32. Galleries of the larvae of *Chlorophorus carinatus* (Cerambycidae), commonly found in the inner bark of many stressed hardwoods and conifers. Olmotonyi, Arusha
Plate 33. Wooden scaffolds as widely used in construction along the coast are often infested by bark and wood borers such as *Philematium virens* (Cerambycidae)

Plate 34.

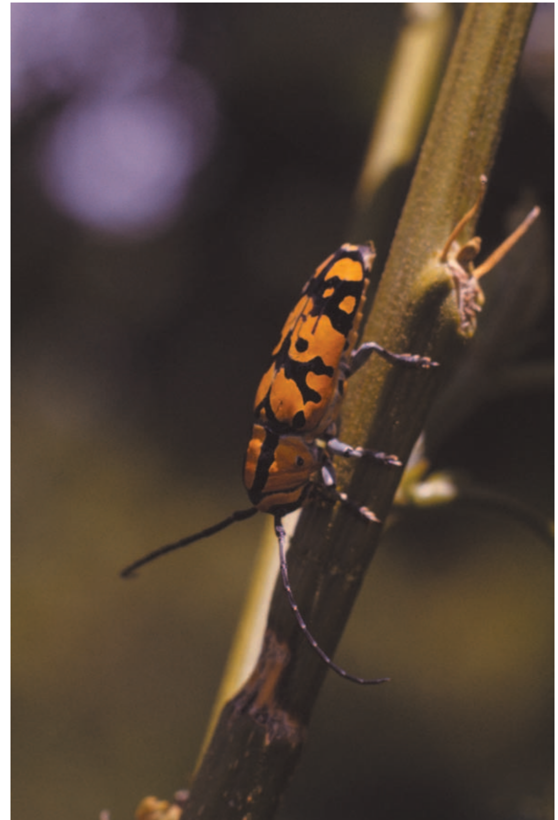

Plate 35.

Plate 34. The branches and stems of many hardwoods between 30 and 80 mm diameter can be girdled by the cashew stem girdler *Paranaleptes reticulata* (Cerambycidae), whose larvae develop in the declining portions

Plate 35. The shoot borer *Tragocephala variegata* (Cerambycidae) attacking succulent shoot of *Albizia lebbeck.* Note girdle just below head

Plate 36.

Plate 36. Dead *Acacia tortilis*, killed by elephant, with numerous exit holes made by hatching Prioninae (Cerambycidae). Manyara N. P.

Plate 37.

Plate 38.

Plate 37. The size of this giant longhorn beetle *Acanthophorus* sp. (Cerambycidae) becomes apparent in a child's hand

Plate 38. Fresh frass is often pushed out in loose cylinders or piles from the galleries of ambrosia beetles, *Xyleborus* sp. (Scolytidae). Early January, Umbwe-Kilimanjaro

Plate 39.

Plate 39. Entrance hole of *Oryctes monoceros* (Scarabaeidae) in young coconut palm. March, Zanzibar Island
Plate 40. Drooping frond of coconut palm damaged by *Oryctes monoceros* (Scarabaeidae). March, Zanzibar Island

Plate 40.

Plate 41.

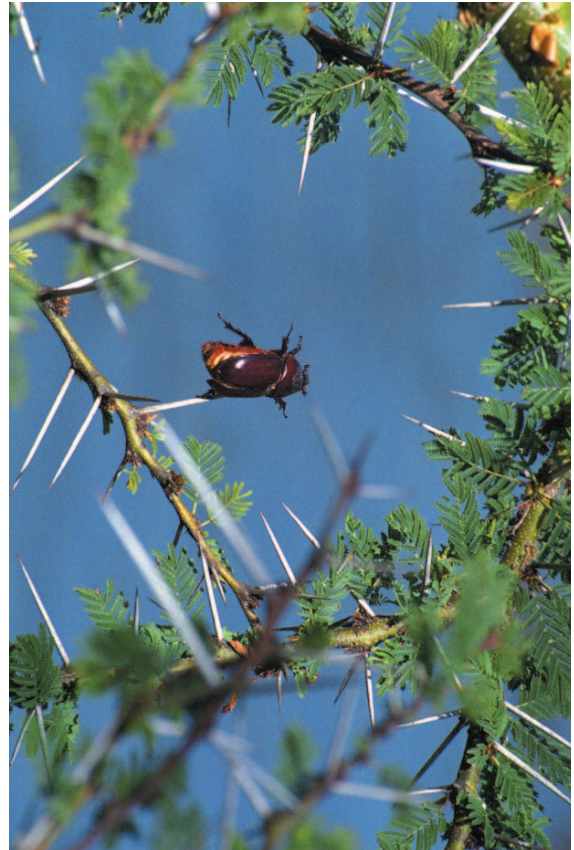

Plate 42.

Plate 41. Harpooning or "winkling" of adult *Oryctes* spp. (Scarabaeidae), a successful if labor-intensive physical control method. March, Zanzibar Island

Plate 42. A living female rhinoceros beetle *Oryctes boas* (Scarabaeidae) impaled on acacia thorn for later consumption by a shrike. Early January, Serengeti

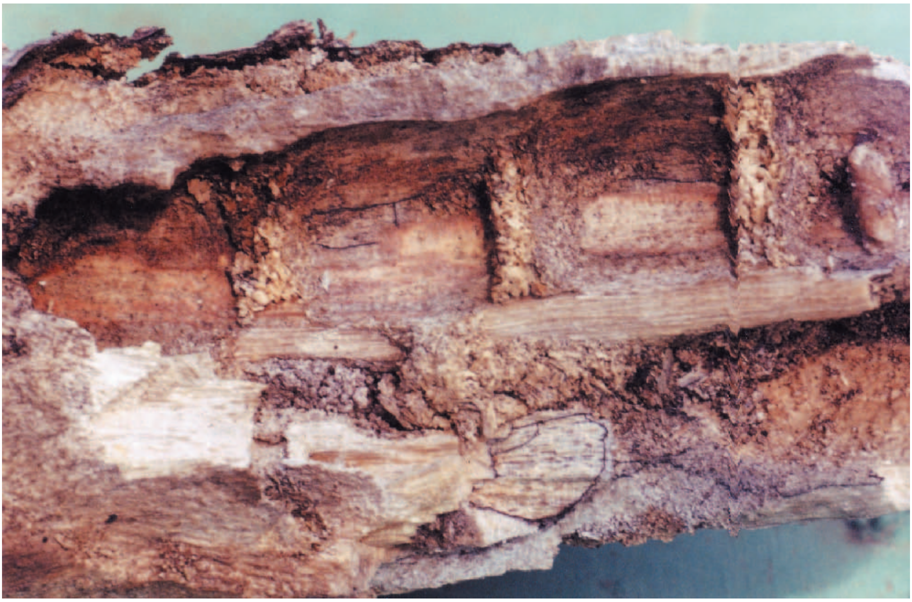

Plate 43.

Plate 44.

Plate 43. Longitudinal section through tunnel of carpenter bee (Xylocopidae), showing cells (empty) and cross walls
Plate 44. Late instar caterpillar of *Xyleutes capensis* (Cossidae) tunneling in branch of *Cassia* sp.

Plate 45.

Plate 45. A pangolin *(Manis temincki)* hunting for ants and termites in burned savanna woodland. Usangu

Plate 46.

Plate 46. Carton nest of cocktail ants (*Crematogaster* sp.) (Myrmicinae) on a sapling of *Cupressus lusitanica*. The terminal above the nest is still green, but shows signs of attack, including resin and rough bark

Plate 47.

Plate 48.

Plate 47. While pseudo-galls are a product of acacia trees themselves, numerous true, insect-caused galls, such as this spiky one, are also common
Plate 48. Pseudo-gall of *Acacia drepanolobium* inhabited by cocktail ants, *Crematogaster* sp. (Myrmicinae). Lemuta, Ngorongoro Conservation Area

Plate 49.

Plate 50.

Plate 49. A turreted termitarium of *Macrotermes subhyalinus* (Termitidae). Makanja, Upare
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Plate 53.

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Plate 55.

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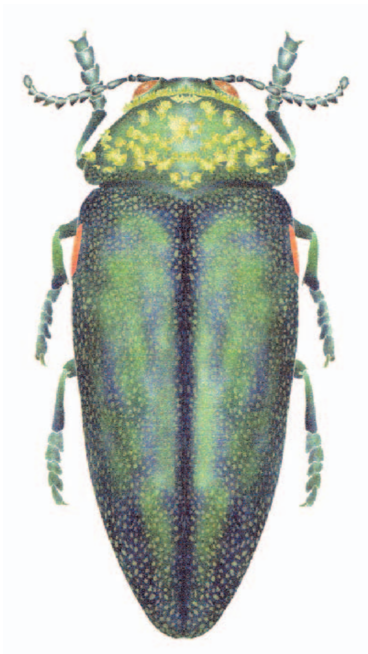
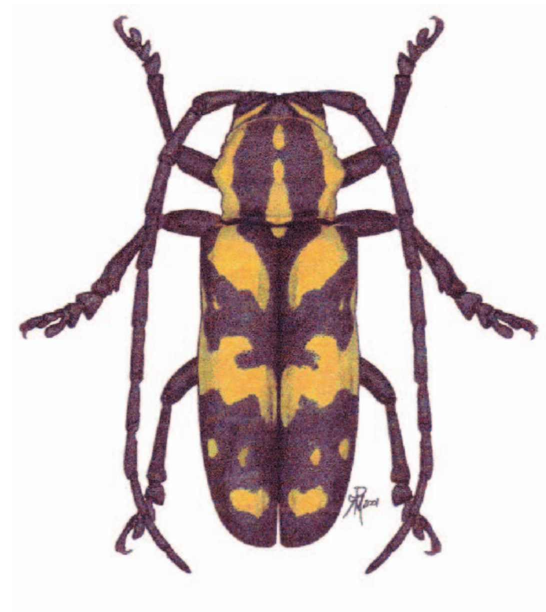


Plate 66.

Plate 67.



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CHAPTER 1

INTRODUCTION TO TANZANIA

1. GENERAL

Tanzania is a country of about 94 million ha, encompassing an area nearly the size of Texas and Colorado combined. Almost half of this territory, 44 million ha, is covered with forests and woodlands, including 1,400,000 ha of natural closed forest, 108,000 ha of mangroves and about 42,500,000 ha woodlands. As of 2005, the population stands at over 37 million, for an average density of about 41.8 people per km^2. However, the populace is unevenly distributed, with major centers of high density along the Indian Ocean coast, in and near some of the mountains and on the margins of Lake Victoria. Approximately two-thirds of Tanzania's citizens live in rural areas.

While the total area figures for woodlands appear impressive, vegetative growth rates are generally very low, and the expanding human population, growing at 1.9% per annum, greatly relies on these forests for fuel, building materials, numerous non-wood forest products, grazing and conversion to agricultural land. As a result, growing pressure on already strained and degraded resources are anticipated.

Deforestation and land degradation resulting from inappropriate agricultural practices already significantly impacted densely populated areas 110 years ago during the German colonial period (Stuhlmann 1895; Schabel 1990). Rodgers (1993) argues that closed forests once covered as much as 20% of Tanzania, 6-7 times more extensive than they are now. Large-scale studies in the Usambara Mountains estimate forest cover reductions of some 60% during the 20^{th} century (Rodgers 1993).

2. PHYSIOGRAPHY AND SOILS

Tanzania is a country of both uniformity and contrasts. It exhibits considerably greater environmental heterogeneity than its tropical location spanning the latitude belt between 1^0 and 12^0 South would suggest. Environmental conditions encompass the full spectrum from tropical islands in the Indian Ocean to the glaciers near the summit of Mt. Kilimanjaro, which is, at 5,895 m, Africa's highest mountain. Included in this territory are also Lakes Victoria and Tanganyika, Africa's biggest and deepest

lakes, located in two branches of the African Rift Valley on the eastern margin of the great rainforest of the Congo. Nearly two thirds of Tanzania is, however, defined by gently undulating plateaus at an elevation of about 1,200 m, interrupted by insular mountain ranges, including very old crystalline and relatively young volcanic formations.

Soils in these plateaus range from deep, rather acid and infertile sandy loams on the crests, to dark clay soils in the shallow valleys and extensive interior basins. In the northeast, slightly alkaline red earths, sandy loams and clays predominate, while along the coast and on the islands a mosaic of sands, clays and coral prevail. The most fertile soils coincide with well-watered, volcanic highlands, as well as lacustrine and alluvial areas.

3. CLIMATE

Tanzania spans three of the six major climatic zones of Africa: wet tropical, dry tropical and Sahelian (Walter 1973). About half of Tanzania receives less than 760 mm of precipitation a year, and 96% receives less than 1,270 mm, making the dry tropical climate zone the predominant one. Small pockets of even drier, Sahelian climate exist in the northeast. Only the highlands, the coast and areas near Lake Victoria are somewhat reliably wet.

Mean annual rainfall varies widely, from about 320-2,400 mm a year, with considerable inter-annual variation making extremely dry or wet years the norm rather than the exception. Climate is dominated by a monsoonal pattern, characterized by two rainy seasons, a short one from October to November and a longer one extending from February to May. In mountainous parts of the country, sharp orographic contrasts between wet and dry microclimates exist. The Uluguru Mts. for instance exhibit a range of annual rainfall, changing, over a few miles, from 600 mm in the western rain shadow to 3,000 mm on the windward eastern slopes. The prevailingly dry climate and unreliable rainfall patterns make water, more than any other environmental factor, the defining natural resource in East Africa. Most major cities in Tanzania have recently experienced water shortages (Rodgers 1993).

4. NATURAL FORESTS

Tanzania spans four phytogeographic regions: the Sudano-Zambesian Region (Afroriental and Zambesian Domain), the Guineo-Congo Region (Usambara-Zululand Domain), the Afromontane Region and the Afroalpine Region (Brenan 1978).

Of these, the first is by far the most significant in terms of area. Tanzania links two vast belts of semiarid country, one extending from Senegal to the Horn of Africa in the North, the other reaching from the Indian Ocean in Mozambique to the Atlantic Ocean in Angola in the South. As in much of the rest of Africa, Tanzania includes three broad habitats, i.e., forest, savanna and desert.

Despite the relative uniformity of vegetation in this semiarid "horseshoe" wrapping around the Congo basin, Tanzania is floristically unique and surprisingly rich, with 12,000 known species, including about 1,200 species of trees. This wealth of interesting flora and resultant fauna is attributable to Tanzania's position at the nexus of several phytogeographic regions, in combination with its great altitudinal and topographic variety, geological history, a strongly seasonal climate, and the proximity of the Indian Ocean and the Rift Valley, which forms an ecological "superhighway" linking it to Eurasia, West Africa and the Gondwana South.

A brief, simplified introduction to the most relevant forest types (Figure 1-1) in Tanzania, ordered from the wettest to the driest types follows (Polhill 1968; Trapnell and Langdale-Brown 1969; Knapp 1973; Lovett and Wasser 1993).

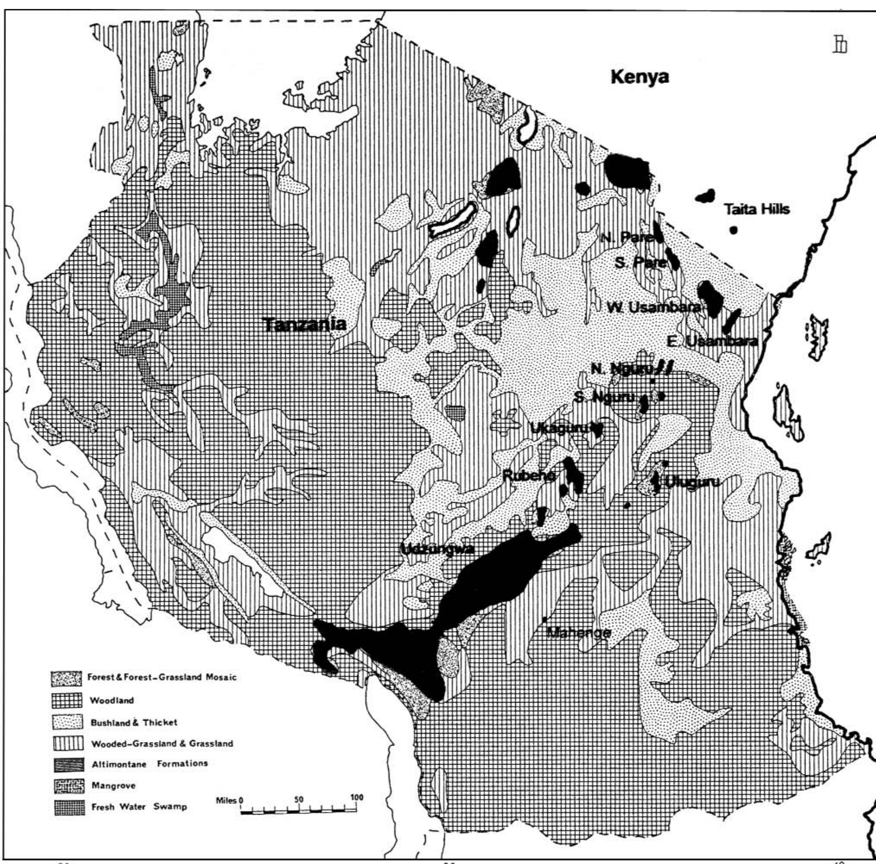


Figure 1-1. Map of vegetation types in Tanzania, highlighting (in solid black) the Eastern Arc Mts. (Composite from Polhill (1968) and Burgess et al. (2002); reproduced by permission of Societas Phytogeographica Suecana and DOF-BirdLife Denmark/WCST-BirdLife Tanzania, respectively).

4.1. Mangroves

These unique forests require brackish or marine water influences and thus are limited to the marine islands, the estuaries of the Rufiji, Ruvuma and Wami Rivers, and the mouths of numerous creeks along the coast from Tanga to Mtwara. Prominent representative trees include eight species of *Avicennia*, *Brugiera*, *Ceriops*, *Lumnitzera*, *Rhizophora*, *Sonneratia* (Figure 1-2) and *Xylocarpus*. Due to the significance of mangroves in providing habitat for marine life, shoreline stabilization, biodiversity and various forest products, Tanzania recently formulated a management plan for conservation and development of these forests, becoming the first African country to do so. In 2000 the country still possessed about 108,138 ha of mangroves, including 53,255 ha fairly unspoiled forest in the Rufiji Delta, one of the largest remaining blocks of mangrove in southern and eastern Africa.

Figure 1-2. Sonneratia alba, one of eight species of mangrove in coastal Tanzania. Bagamoyo.

4.2. Closed Forests

Closed forests are another limited forest type covering only 2-3% of Tanzania's land area. In 1979 there were a total of 1,300,000 ha of such forests in Tanzania, of which 7,892 were reserved (Rodgers 1993). There are several distinct types along moisture and altitudinal gradients.

4.2.1. Moist Lowland Forest (Lowland Rain Forest)

This type is restricted to the foothills of the eastern mountains, to areas along Lake Tanganyika and to the Bukoba District. Dominant trees include *Cephalosphaera*,

Allanblackia, Isoberlinia, Macaranga, Newtonia, Parinari and *Chrysophyllum,* amongst numerous co-dominants (Figure 1-3). Many of these forests provide a continuum with the coastal forest mosaic and their precise classification is still debated.

Figure 1-3. A lush lowland rain forest composed of trees such as *Newtonia, Sterculia, Khaya,* among many other species, including, as in this picture, *Pandanus engleri* near springs and stream. Kimboza Catchment Forest Reserve on the East slopes of the Uluguru Mts., Morogoro District.

4.2.2. Moist Montane Forest (Upland Rain Forest)

This type occurs at altitudes from 1,200-3,000 m in areas of moderately high rainfall or recurrent mist. Dominant trees include *Aningeria, Parinari* and *Ocotea* with admixtures of *Podocarpus* (Figure 1-4; Plate 1), *Chrysophyllum, Cassipourea, Polyscias, Tabernaemontana, Macaranga, Neoboutonia, Nuxia, Hagenia* and *Myrica*.

Figure 1-4. Upland rain forest on the drier side of the moisture spectrum, composed of *Podocarpus falcatus, Juniperus procera* and associates. Mt. Meru crater.

4.2.3. Dry Lowland Evergreen Forest (Lowland Evergreen Forest)
This type (Figure 1-5) is associated with irregularly distributed rainfall. Characteristic trees include *Albizia, Brachylaena, Chlorophora, Cynometra, Lannnea, Manilkara, Pteleopsis, Sclerocarya* and *Stuhlmannia.*

Figure 1-5. Dry lowland, semi-evergreen forest with partly deciduous species. This climax forest on the drier slopes of the Eastern Arc Mountains has a moderately high canopy dominated by *Manilkara sulcata* over numerous associates. Kitulanghalo Catchment Forest Reserve, Morogoro.

4.2.4. Dry Montane Evergreen Forest (Upland Evergreen Forest)
This type occupies exposed locations and rain shadow aspects of Tanzania's larger mountains. They typically include *Juniperus procera* (Plate 2), *Olea* (Figure 1-6), *Ilex, Agauria, Cassipourea, Nuxia* (Plate 3) and *Ekebergia*.

Figure 1-6. Upland evergreen forest including *Olea hochstetteri*, a valuable timber species. Ngurdoto crater, Arusha N. P.

4.3. Deciduous Woodlands

Open forests, those without crown closure, cover vast areas of Tanzania and are concentrated in the western, central and southeastern parts of the country. Included are the so-called "miombo" woodlands mainly composed of species of *Brachystegia, Julbernardia, Isoberlinia* and *Pterocarpus* (Figure 1-7; Plate 4), or similar woodlands dominated by other legumes such as *Acacia* (Plate 5), *Millettia, Dalbergia* and *Lonchocarpus.* Interspersed with these woodlands are wooded grasslands and groundwater-influenced riverine or riparian gallery forests (Figure 1-8). Depending on the degree of crown closure, the woodlands grade from "savanna woodlands" to "woodland savannas", to fully edaphic or cultural savannas, which result from seasonal flooding (dambos and mbugas), or excessive and prolonged burning, cutting,

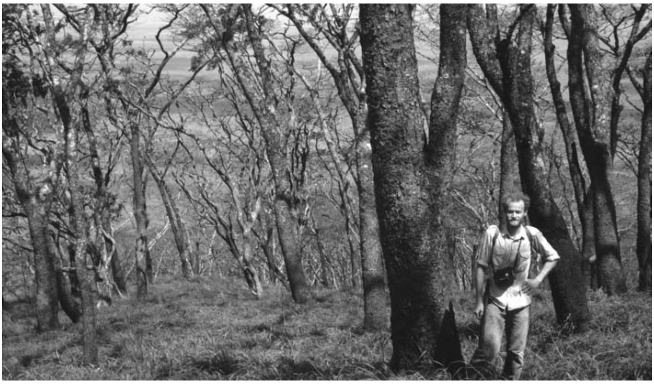


Figure 1-7. Savanna woodland of the miombo type composed mainly of tree legumes. Early November, Nguru ya Ndege, Morogoro.

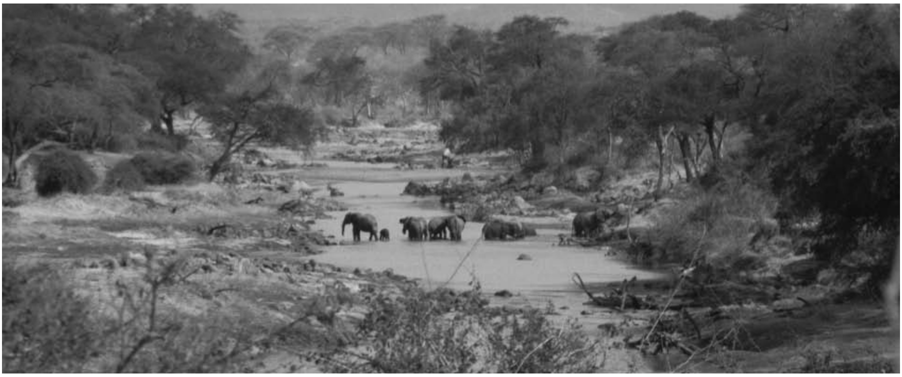


Figure 1-8. Acacia woodlands along the Ruaha River. Late September, Ruaha N. P.

grazing and agriculture, respectively. Common species include certain palms *(Hyphaene* and *Borassus*), as well as species of *Acacia, Combretum, Terminalia,* and *Dombeya,* most of which exhibit adaptations to fire and drought (Figure 1-9).

Figure 1-9. Woodland composed of many species of low-growing woody plants. Northern Selous Game Reserve.

4.4. Bushlands and Thickets

In the central and southeastern Plateau regions where rains are limited and soils are poor, there are extensive areas of mostly low-growing trees and shrubs in often dense arrangements. They include species of *Acacia, Combretum, Commiphora, Croton, Dalbergia*, *Delonix*, *Diospyros*, *Dombeya*, *Grewia*, *Hippocratea*, *Markhamia*, *Lannea*, *Strychnos*, *Teclea* and *Terminalia* (Figure 1-10). However, the giant

Figure 1-10. Newly burned savanna bushland mostly composed of *Combretum* spp. and *Dalbergia melanoxylon.* Intense, late season fires such as this one are frequently hot enough to damage the woody vegetation, and predispose the trees for bark and wood borer attack. Late August, Dakawa, Morogoro.

Adansonia digitata (Plate 6) also makes a stand here. Fire (Plate 7) and drought are dominant forces in the dynamics of this vegetation type. Some of these communities transition into desert-like vegetation or degraded land, dominated by *Euphorbia* and other succulents (Plate 8).

5. MAN-MADE FORESTS

Besides natural forests, Tanzania also has artificial ones. Included are plantations mostly managed by the state, as well as rural development forests (RDF) in the form of community woodlots and private agroforestry. Shade trees are valued components of rural and urban communities and homesteads.

5.1. Plantations

Since German colonial days Tanzania has experienced several waves of plantation emphasis (Schabel 1990, 1992; Rodgers 1993; Burgess and Mbwana 2000). These were driven in part by profit motives, but also by attempts to meet growing demand for wood products while protecting natural forest or restoring degraded and fallow land to forest. By the late 1960s, a total of 80,000 ha in plantations existed in Tanzania (Polhill 1968). Of these, some 18,500 ha were in exotic softwoods, mostly species of *Pinus* and *Cupressus* in the southern and northern highland regions (Figure 1-11). Significant planting of softwoods continued into the 1980s. Exotic hardwood

Figure 1-11. Species of exotic cypress *(Cupressus)* and pines *(Pinus)* have been the main plantation conifers in Tanzania for decades. Rongai, Kilimanjaro.

plantations in the foothills of the East Usambaras, Pugu Hills, Ruvu North, Vikindu and on the Rondo Plateau, largely emphasized teak (*Tectona grandis*) (Figure 1-12) and species of eucalypts (*Eucalyptus*) (Burgess and Mbwana 2000). Only one major native hardwood species, *Cephalosphaera*, is successfully grown in plantations (Rodgers 1993).

Figure 1-12. Plantations of exotic teak *(Tectona grandis)* have remained relatively unplagued by insect pests, but often suffer damage from wildlife. Korogwe.

The costs and benefits of tree plantations have been debated for years, as well as the relative merits of native vs. exotic species, usually pitting economic interests of industries or the state against non-governmental organizations (NGOs) representing more ecological and social emphases for forest management (Anon 1999). The 1998 Montevideo Declaration, a joint statement from many NGOs, advocated a halt to large-scale plantation development, but was countered by arguments supportive of plantations in a complementary role to natural forests (Evans 1998). Still, the debate about plantations is far from over. Critical questions focus more on the broader social and environmental impacts, than on their potential for sustainable yield (Anon 1999) or for problems with pests (Browne 1968).

Tree planting programs involving monocultures, reliance on exotics, and poor site/species matches have in fact significantly contributed to the increasing frequency and severity of pest problems in Africa in general (Wagner et al. 1991; Murphy

1998), as well as other parts of the tropics (Gray 1972; Schabel et al. 1999; Nair 2001; Speight and Wylie 2001). Altogether, 60% of tree plantations in Africa are judged unsuitable for commercial wood supply, primarily due to difficult sites that predispose trees to attack by pests (Anon 1999).

Despite such difficulties, plantations continue to constitute an important part of Tanzania's forestry program. Acreages presently amount to 133,000 ha, of which 13,000 ha are in acacias, 35,000 in pines, 3,000 in eucalypts and 82,000 in other species. The enormous growth potential of certain exotic species, yielding as much as 40 m^3 of wood/ha/year, as opposed to natural forest with up to 5 m^3, taken together with the still growing demand for wood-based products, suggests that plantation forestry in Tanzania will continue to be important. The acquisition in 1992 of 28,132 ha of land in the Kilombero and Ulanga Districts by the Kilombero Valley Teak Co., a private firm, with a total of 14,000 ha potentially targeted for the culture of teak (Figure 1-12) was justified as an attempt to reduce pressure on natural forests, while priming local economic enterprises (Bekker et al. 2004). Although teak in Tanzania is relatively free of insect pests or diseases, some damage from baboons and elephant has been experienced in some of the newly established plantations.

Contemporary forest management policy in Tanzania emphasizes plantation expansion to degraded and fallow lands and greater reliance on native tree species, rather than conversion of existing natural forest and afforestation with exotics (Rodgers 1993). It is doubtful, however, that this will guarantee trouble-free plantations. While a recent study concluded that tropical tree plantations are at generally greater risk of pest outbreaks than natural forests, plantations of exotics are considered to be at no greater risk than plantations of indigenous tree species (Nair 2001).

5.2. Rural Development Forests (RDF)

While most plantations are privately or state-owned, they are also important components of community and social forests. Like other countries in dry-land Africa, Tanzania heavily relies on woody fuels to meet energy needs (Plate 9). It is estimated that over 90% of energy consumption in the country is wood-dependent. Traditionally this use was unregulated and primarily affected forests and woodlands in relative proximity to settlements. In the late 1960s, when it became clear that this opportunistic extraction of wood from slow-growing natural forests was increasingly commercialized and exceeded the long-term sustainable harvest level by a factor of as much as 2:1, a community afforestation program was begun. Between 1975-1981, a total of about 50,000 ha of village fuel wood plantations (Figure 1-13) were established, partially, but not completely meeting the challenge posed by continuing deforestation. Since overexploitation of natural forests in the vicinity of urban areas such as Dar es Salaam, Dodoma and Mbeya was particularly rampant, municipal forestry projects were also started there, essentially urban versions of the village afforestation efforts.

Figure 1-13. A fuel wood plantation of *Eucalytpus camaldulensis* scorched in late season fire. The larger trees recovered, but, in the presence of eucalyptus borers (*Phoracantha* spp.) could be susceptible to attack. September, Morogoro.

Rural development forests, as increasingly emphasized since the early 1980s, now not only encompass the promotion of community and social forests, where natural forests and/or plantations are managed by or on behalf of communities, respectively, but also agroforestry, often in private or joint ownership.

In many parts of the tropics, including Tanzania, agroforestry is an age-old land management system. The main merit of this land use practice is, that it potentially allows the intensive and sustainable use of a particular plot of land for simultaneous or sequential production of a great variety of agricultural and horticultural crops, wood and non-wood forest products, and often livestock. This multi-cropping system in its agro-silvicultural dimension is particularly well suited to humid and montane environments, while silvo-pastoral systems are generally better suited for semiarid conditions.

Because of their potential to address many of the needs of the growing ranks of rural subsistence farmers, first attempts to optimize these systems by turning agroforestry into a science were made in the 1970s. Since then, largely as a result of the establishment of the International Center for Agroforestry Research (ICRAF) in Nairobi, Kenya, much knowledge has been gained. Two well-known agroforestry applications in Tanzania, the home gardens (kihamba) on private lands at Kilimanjaro (Figure 1-14; Plate 10) and the shamba system, a form of taungya forestry on state

Figure 1-14. Forest-like appearance of multi-layered Chagga home gardens from a distance, including trees such as *Rauvolfia, Albizia* and *Grevillea,* among others, over banana, coffee and many other agricultural crops. Marangu, Kilimanjaro.

land in the northern highlands (Figure 1-15), include particularly heavy reliance on woody companion plants. The shamba system is unique in that it provides for agricultural use in tree plantations in a "land for labor" deal, while to some extent addressing population pressures. The important role of the Chagga home gardens as a refuge for both generalist forest species and endemic invertebrates was recently documented with a focus on Saltatoria (Hemp 2005).

Figure 1-15. Shamba agroforestry, a taungya system, incorporates agricultural crops such as beans, corn and potato in a plantation of pruned *Pinus patula.* Rongai, Kilimanjaro.

Pest and beneficial insects associated with agroforestry systems are increasingly being scrutinized (Mchowa and Ngugi 1994; Rao et al. 2000). It is generally agreed that increased plant diversity (polyculture) and complex structure may have a moderating effect on certain pests, while favoring their antagonists (Janzen 1972). At the same time, the narrow genetic base for engineered crops and the prevalence of legumes in agroforestry, may provide a larger and more attractive food supply. The juxtaposition of herbaceous and woody hosts also possibly provides alternate or escape hosts for various pest insects and diseases. On the other hand, it may offer opportunity to exploit trap crops against certain pests, to establish barriers to pest movement, and to use masking odors to advantage. As the introduction of new crops may facilitate accidental introductions or the spread of new pests, prior studies of entomological compatibility between various trees and crops are considered essential (Mchowa and Ngugi 1994).

6. PROTECTED FORESTS

The relative integrity of many of Tanzania's forests in pre-colonial days may have been largely a function of low, and periodically even declining human populations, limited technology and the remoteness of potential markets. Traditional extraction of resources appears to have been largely opportunistic and shortages may have simply been addressed by periodic migration. Formal attempts to safeguard specific forests were apparently limited to some protected, sacred groves (Hamilton and Bensted-Smith 1989; Mgumia and Oba 2003).

While the first century of scientific forestry in Tanzania was to a great extent focused on production, the service functions of forests were never completely ignored (Schabel 1990,1992; Rodgers 1993). There were, however, episodic shifts in policies favoring production over protection. Currently, managers are seeking to balance the two, usually by designating different areas with an emphasis on either production (plantations), conservation (forest reserves), or preservation (parks).

During the last 25 years, traditional forest protection and production objectives have increasingly been influenced by infusions of rural development forestry policies. Equally significant was legal recognition of biodiversity as a mandate for management. The "Tanzanian Forest Action Plan" (TFAP) of 1988 and the new Forest Act of 2002, declared the enhancement of the forestry contribution to sustainable use and development of the country's land resources to be the overriding strategic goal for future forest management. This emphasizes land protection for water, climate and conservation values, as well as afforestation and reforestation for woody fuels, commercial timbers and non-wood forest products. A watershed management approach is the likely solution for integrating such broad forestry objectives with other land use (Rodgers 1993).

6.1. Forest Reserves

Early colonial foresters documented that forest depletion and degradation were already evident in certain areas of Tanzania by the end of the 19th century (Schabel 1990,1992). For instance, coastal mangroves and forests in the neighborhood of a young and growing Dar es Salaam were judged "ruthlessly exploited" and "almost completely devastated" due to excessive cutting, burning or grazing. The "magnificent" forests of eastern Usambara were reported to have "largely vanished" and fuel wood shortages were commonplace not only near the cities, but also in some rural areas, such as near the bigger villages in western Usambara. High local demand, generally easy access or connection to markets via caravan routes and the sea were common denominators. Concurrent with forest depletion, river flows, such as those of the Kingani in the Uluguru Mountains, had begun to discernibly diminish in those years (Stuhlmann 1895). Uncontrolled forest exploitation accelerated, when European settlers started impacting forests on or near their newly occupied estates, and through voluminous fuel wood cuts associated with construction of the new railways.

In response to these pressures on forests, the German colonial government issued numerous ordinances, edicts, and decrees to effect forest protection (Schabel 1990, 1992). The most significant and lasting legacy of these policies was the establishment of almost three-quarters of a million ha of forest reserves, mostly in the eastern mountain ranges. The motives were primarily environmental (hydrology and climate), secondarily fiscal. In fact, investments associated with the establishment and administration of these reserves largely accounted for persistent deficits in the forestry budgets. It was also during this time that the significance of mountain forests for biodiversity was first recognized (Gerstaecker 1873; Sjöstedt 1910).

Subsequently, shifts in forest policies led to alternating periods of greater emphasis on either protection of forests, or on production that extended through the British era and beyond (Rodgers 1993; Burgess and Mbwana 2000). After World War II, and then again in the 1970s, the production component gained momentum. By the late 1960s, forest reserves totaled 1,050,000 ha of closed forest and another 10,5000,000 ha of dry forest and woodland (Polhill 1968). In the first 20 years of independence, Tanzania increased its forest reserve estate by some 1,370,000 ha, while revoking 60,500 ha for agricultural development. Unfortunately, enforcement of the law (Figure 1-16) was generally lax (Rodgers 1993).

Figure 1-16. Sharp transition between crop areas and the North Uluguru Forest Reserve, showing human encroachment into the protected area. Mid-1980s.

6.2. Protected Areas

Tanzania's sizable forest reserves are complemented by numerous other protected areas such as national parks, conservation areas, game reserves, nature reserves and game controlled areas, where the main focus is the preservation of Tanzania's extraordinary landscapes and biodiversity. In 1951, Serengeti became the first national park on Tanzanian territory and in 2001 the Kitulo Plateau National Park became the latest. Tanzania has ratified all major international conventions and agreements concerning natural resources, and currently has 25% of the national territory under some kind of protection, exceeding international standards for nature conservation and commitment to biodiversity.

7. ENDEMISM

The great age, isolation, altitudinal range and fragmented nature of the eastern African forests have combined to produce remarkably high levels of endemism and diversity in various groups of taxa (Lovett and Wasser 1993). Since the late 1980s, Tanzanian "hotspots" of biological diversity have been recognized for having not just local but international significance (Stuart et al. 1990; Myers et al. 2000; Küper et al. 2004; Burgess et al. 2004a). The designation hotspot allows prioritization of efforts to conserve species and habitats and thus has the potential to reduce the anthropogenic mass extinctions presently underway by a third (Myers 2003). Recent conservation initiatives by BirdLife International, Conservation International and the World Wildlife Fund (WWF), among others, concern themselves with rare and endangered flora and fauna and thus focus special attention on some of these hotspots or critical ecosystems in Tanzania.

In conjunction with attempts to define hotspots, the WWF's analysis of "Global 200 Eco-regions", resulted in much of Tanzania being mapped as globally important for biodiversity, and being assigned conservation priority class I status (Burgess and D'Amico 2002; Burgess et al. 2004a). Worldwide there are 900 eco-regions, i.e., relatively large conservation units of regional or global significance. Of these, 104 are located in mainland Africa and 14 in Tanzania (more than any other country in Africa), including some important forest-based global priority eco-regions such as the Albertine Rift montane forest, the Central and Eastern miombo woodlands, the East African mangroves, the East African coastal forests, the Eastern Arc montane forests, and the Southern Rift montane woodlands.

The flora of Tanzania has been extensively inventoried. In an overall assessment of plant endemism for tropical Africa, Tanzania was recognized as one of two "especially rich" areas. Dividing the number of its endemic plant species ($E = 1{,}122$) by the total area in km^2 (A), gives Tanzania an Area-Endemism Index (AEI) of 837, and Zanzibar, with five endemics, an AEI of 327 (Brenan 1978). Insular pockets of wet tropical forest near the coast, in the mountains and near Lake Victoria, account for much of this endemism (Lovett and Wasser 1993), the former two having received

significant attention during the 1990s. By considering all biota, Tanzania earned a globally outstanding biological distinctiveness index (Burgess et al. 2004a).

7.1. Eastern Arc Mountains (EAM)

By far the most interesting and diverse flora of Tanzania is found in the block of mountains in the East of the country, referred to as the Eastern Arc Mountains (EAM) (Rodgers and Homewood 1982; Hamilton and Bensted-Smith 1989; Lovett and Wasser 1993; Depew 1998; Burgess et al. 2004c). From North to South these include the Pare, Usambara, Nguru, Ukaguru, Uluguru, Rubeho, Malundwe, Uzungwa, Mahenge and most of the southern highlands (Figure 1-1). Among the 25 hotspots of biodiversity worldwide, this is the smallest and most fragmented (Myers et al. 2000). The EAM are acknowledged as "some of the most biologically interesting areas in the world" (Lovett 1989), and as the richest forests for biodiversity in mainland Africa (Depew 1998). They provide a congruence of 0.5% of plant and 0.4% of vertebrate species worldwide (Myers et al. 2000). Endemism for lowland and groundwater forests associated with these mountains (not included were coastal forest flora, the mangroves and the forest flora near Lake Victoria) amounted to 2,085 species of plants in 801 genera with 509 forest species endemic to Tanzania. The degree of endemism in these areas is thus 24.4% of the total forest flora. Of the endemics, 93% occur in EAM forests (Lovett 1989). These forests have also been documented as having tremendous capacity to store carbon and thus potentially could help mitigate carbon emissions associated with anthropogenic climate change (Munishi and Shear 2004). Presently, there are attempts to designate the EAM as a World Heritage Site (Burgess et al. 2004c).

7.2. Coastal Forests (CF)

In addition to the EAM, the highly fragmented coastal forests (CF) of Tanzania and Kenya (Figure 1-17) have been the focus of intense interest for conservation biologists

Figure 1-17. Close-up of a coastal forest, composed of many tree species, including this strangler fig (*Ficus* sp.) Mvuha, East Uluguru foothills, Morogoro.

(Howell 1981; Burgess and Clarke 2000; Burgess et al. 2003, 2004b). Together with the EAM, the CF are listed as one of the eight "hottest hotspots" globally, because they contain numerous endemic biota per 100 km^2, their primary vegetation has shrunk to 6.7% of their original extent and they appear three times among the top 10 for each of five factors used in the designation of priority hotspots (Myers et al. 2000).

The rate of endemism for the CF vascular forest flora is 37%. Among vertebrates it is 57% for forest reptiles, 36% for forest amphibians, 10.5% for birds and 7.1% for mammals. In total, 786 known species in eight biological groups are strictly endemic to the CF (Burgess 2000). Single-site endemism is common there. The nine centers of endemism located in the Tanzanian CF each contain over 100 endemic species. Over the past 12 years, eight new species of mammals, two new species of reptiles and a new species of amphibian were discovered in the CF.

7.3. Animal Endemism

Given their stationary nature and relative permanence, plants in Tanzania have to date received the bulk of attention by conservation biologists, followed by birds (13/1,016 endemic), mammals (13/310 endemic), reptiles (56/245 endemic) and amphibians (40/121 endemic). Based on their proximity to the coast and to research facilities at Amani and Morogoro, the Usambara and Uluguru Mountains may at this time be the overall best researched areas of Tanzania for all types of biota. The Ulugurus were recently ranked at the highest level of importance, based on their dual significance for water supplies in Dar es Salaam and for biological values in general. They are considered the third most important area for conservation of endemic fauna in the EAM, and one of the 10 most important tropical forest sites for conservation on the continent. Besides 135 endemic plant taxa, the Ulugurus alone harbor at least 16 endemic vertebrates, 11 endemic reptiles and amphibians, and 2 endemic mammals (Burgess et al. 2002).

Although plant diversity is generally well correlated with the diversity of invertebrates, and hotspots generally contain sizeable numbers of endemic invertebrates, the enormous diversity of invertebrates and their conservation status in Tanzania has barely been accounted for at this time. Much of the limited knowledge available is based on EAM and CF studies. Certain groups of mollusks attain about 75% and 79% endemism in these two areas, respectively (Howell 1989; Verdcourt 2000). Millipede (Diplopoda) endemism for the EAM, CF and Tanzania altogether, is consistently over 76%, and in forest species, over 80% (Kraus 1958; Rodgers and Homewood 1982; Hoffman 1993, 2000; Sørensen 1995). Among arachnids, 88% of harvestmen (Opiliones) in the Uluguru Mts. (Scharff et al. 1981) and over 80% of linyphiid spiders were endemic on individual mountains in the Eastern Arc (Scharff 1992, 1993). For various groups of insects (Table 1), species endemism ranges from 5.75% for certain Orthoptera in the geologically young volcanic region of Kilimanjaro, to at least 90% of earwigs (Dermaptera), over 90% of ground beetles

Table 1-1. Insect endemism in Tanzania.

Taxonomic Group	*# endemic (# total) species*	*% endemic species*	*% endemic genera*	*Location*	*Reference*
Acridomorpha (Orth.)	111 (416)	26.6	9.7	Tanzania	Johnsen & Forchhammer 1975
Carabidae (Col.)		90	18	Uluguru Mts.	Berger & Leleup 1971
	40 (42)	95		Uluguru Mts.	Scharff et. al. 1981
Dermaptera	9 (10)	90		Uluguru Mts.	Scharff et. al. 1981
	31 (102)	30.4		Tanzania	Haas & Klass 2003
Pselaphidae (Col.)		100	31	Uluguru Mts.	Berger & Leleup 1971
	27 (27)	100		Uluguru Mts.	Scharff et. al. 1981
Rhopalocera (Lep.)	10 (37)	27		Uluguru Mts.	DeJong & Congdon 1993
	75 (400)	18.7		Coastal Forest	Burgess & Clarke 2000
	121 (1370)	8.8		Tanzania	Sholtz 2000
Saltatoria (Orth.)	11 (191)	5.75		Mt. Kilimanjaro	Hemp & Hemp 2003
Sphecidae (Hym.) (all spp.)	27 (131)	21		E. Usambara Mts.	Rodgers & Homewood 1982
" (forest spp. only)	27 (74)	37		E. Usambara Mts.	Rodgers & Homewood 1982
Tenebrionidae (Col.)	17 (47)	30		Uluguru Mts.	Scharff et al. 1981

(Carabidae) and an astonishing 100% for Pselaphidae (Coleoptera), in the ancient Uluguru Mts. Altogether, 30.4% of Dermaptera in Tanzania are endemic (Haas and Klass 2003). Except for some butterflies (Rhopalocera), many endemic species of insects and other invertebrates are single mountain endemics.

Although rates of endemism tend to be highest in wingless and/or ancient taxa, many being closed-forest specialists (Burgess et al. 1998; Burgess and Clarke 2000), some winged insect groups also exhibit a degree of endemism and occasionally yield undescribed species, such as various recently discovered katydids (Figure 1-18) (Hemp 2001b,c). Also,37% of forest species of sphecid wasps collected in East Usambara are endemic (Rodgers and Homewood 1982), and of the 400 species of CF butterflies about 19% are endemic, including two recently discovered species restricted to the East Usambara lowlands (Burgess and Clarke 2000). Among two endemic dragonflies in Tanzania, one species from the Usambara mountains represents a monotypic genus (Clausnitzer 2001). Recently, a new insect order, Mantophasmatodea, was described, including the new family Tanzaniophasmatidae, with a new genus and species, *Tanzaniophasma subsolana* (Zompro et al.) (Figure 1-19) from Tanzania (Klass et al. 2002, 2003). While this order, called heelwalkers, contains 13 extant species, *T. subsolana* is the only species occurring outside of southern Africa and is known exclusively from one museum specimen collected in Ufipa District, Tanzania in 1950. The heelwalkers are wingless predators that combine certain morphological characteristics of preying mantids and walking sticks.

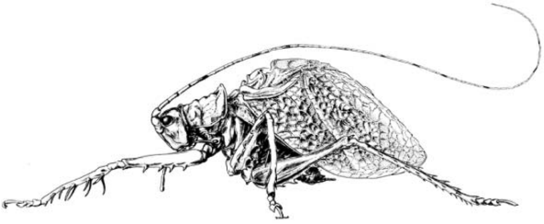


Figure 1-18. Aerotegmina kilimandjarica (Tettigoniidae), a Kilimanjaro endemic. (From Hemp 2001b; reproduced by permission of A. Hemp).

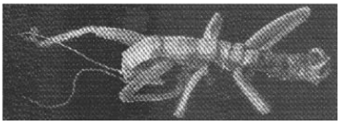


Figure 1-19. The predacous heelwalker *Tanzaniophasma subsolana*, a newly described species from southwestern Tanzania, representing a new genus and the new family *Tanzaniophasmatidae* in the new order *Mantophasmatodea.* (Reprinted with permission from Klass K-D, Zompro O, Kristensen NP, Adis J (2002) Mantophasmatodea: a new insect order with extant members in the Afrotropics. Science 296; 1456-1459. Copyright 2005 AAAS.).

Altogether, 169 species of endemic invertebrates are known from the Uluguru Mts. alone, and there are a minimum of 265 single mountain endemics in the EAM (Burgess et al. 1998). While the overall level of invertebrate richness in Tanzania is only considered to be medium-high (Burgess et al. 2004a), this probably still adds up to more than the 60,000 insect species estimated for this country (Moffett 1958). The total number of insect species for Africa is now estimated to be around 150,000 (Miller et al. 2000).

CHAPTER 2

HISTORY OF FOREST ENTOMOLOGY IN TANZANIA

1. PRE-COLONIAL PERIOD (BEFORE 1891)

Starting with the arrival of Vasco da Gama in the late 1400s, Europeans began exploring first the East African islands and the coast, then increasingly the hinterland. The first missionaries arrived in the 1840s, followed by explorers in the 1850s and, finally, imperialists in the 1880s. Their motives included the establishment of missions and trade posts, pure adventures as in search for the source of the Nile and other *terra incognita*, anthropological and natural history investigations, as well as clandestine explorations to set the stage for dominion.

Many safaris venturing into territories hitherto unknown to Europeans not only returned with accounts of the lands and indigenous peoples, but also with specimens of flora and fauna of interest to the scientific world. This included megafauna as well as insects and other arthropods. Some of these safaris collected opportunistically, while others focused more on supplying specific groups of organisms to experts, who would later assess them in remote laboratories, libraries, and museums and describe numerous species new to science.

While most of the early collectors in what is now Tanzanian territory were German, a few were British and one was French. The first scientific explorations that included arthropods were those of Baron Carl Claus von der Decken, whose expeditions in 1862 and 1865 pioneered the scientific exploration of Mt. Kilimanjaro (Decken 1869/71). On his second safari to Uchagga, the baron was accompanied by a particularly avid collector of insects and other arthropods, Dr. O. Kersten. Many of the specimens from this expedition, together with others collected by C. Cooke in Zanzibar in 1864, and Dr. G. A. Fischer, who in 1877, 1878, 1882 and 1883 had traveled through Maasailand, were described and beautifully illustrated (Plate 11) in Gerstaecker (1870, 1873, 1884). Of the 737 species of insects collected by Decken/Kersten, 415 proved new to science (Gerstaecker 1873). Other expeditions were to follow through the 1880s and into the 1890s, including those by H. H. Johnston, G. Volkens and Dr. H. Meyer to Kilimanjaro. Other significant contributors of specimens during that time included J. M. Hildebrandt, von Kalckreuth,

Dr. Böhme, P. Reichhard, Kaiser, Dr. Baumann, LeRoy, von Höhnel, von Wissmann, Emin Pasha, Dr. Stuhlmann, O. Neumann, C. W. Schmid, Pachinger, Dr. Brauns, M. G. Revoil and Völtzkow. These individuals collected in various regions between the coast and Lake Tanganyika, as listed or mentioned by Harold (1878), Peters (1878), Waterhouse (1885), Fairmaire (1887) and Möbius (1898).

Most of the specimens obtained were housed in museums in Berlin, Vienna, London and Brussels (Volkens 1897b). Based on these early collections, Möbius (1898) listed the following number of species known from East Africa in the mid-1890s: scorpions (5), Neuroptera (38), Hymenoptera (233) and Coleoptera (3,195). Möbius distinguished five zoogeographical regions in East Africa, including (1) northern and (2) southern savanna and bush country (3) mountain forests (4) Lakes region and (5) high mountains, apparently failing to acknowledge the uniqueness of the coast. This probably reflected Gerstaecker (1873), who had characterized the insect fauna of Zanzibar and the Coast as being widely distributed and of a certain uniformity. At the same time, Gerstaecker acknowledged "a strange admixture in the fauna due to the isolated and very high Kilimanjaro, … (where) already a 1,700 m altitudinal difference leads to a considerable modification, with not only new, but unique species". He also quantified the connections of the insect fauna from East Africa with southern Africa (171 species), Mozambique (105), Capeland (104), Senegambia (102), Guinea (89), Ethiopia (44), Madagascar (33) and Angola (26), in addition to zoogeographical connections beyond Africa.

From a historic point of view, subsequent science-based forest entomology in a narrower sense can be conveniently subdivided into four periods: German colonial, British colonial, post-independence and post-Rio. Embedded in these periods was a sequence of eras when the emphasis shifted from pests of exotic trees to termites, wood borers, defoliators, exotic invaders, agroforestry pests and biodiversity, respectively.

2. GERMAN COLONIAL PERIOD (1891-1919)

As an initially reluctant participant, Germany entered the scramble for Africa rather late in the 1880s, but then decisively took control of German East Africa (including contemporary Burundi, Rwanda and mainland Tanzania) in 1891. During about 25 years of effective land tenure, German foresters set the stage for professional forestry in that territory (Volkens 1897a; Anon 1902; Schabel 1990, 1992). Their accomplishments included extensive inventories and utilitarian assessments of native trees, aggressive testing and distribution programs for mostly exotic tree species under a variety of conditions, a forceful afforestation program on degraded sites (Figure 2-1), a modest program of silvicultural experimentation with native species, the gazetting and safeguarding of three quarters of a million hectares of fiscally and environmentally crucial forest reserves (Figure 2-2), and the protection of plantations and reserves from destructive agents.

Figure 2-1. As a result of serious degradation, the Germans prohibited burning, grazing and cutting in the “Sachsenwald” Reserve (Pugu?) near Dar es Salaam, and planted native trees where necessary. Within five years, they successfully restored this woodland to satisfactory condition. (From Meyer 1909).

Figure 2-2. Both German and British colonial governments protected numerous fiscally and environmentally important forests and woodlands as forest reserves, such as this submontane rain forest on the east side of the Nguru F.R. (Photo Redslob from Anon 1913).

With respect to the latter, protection from fires and human encroachment received the bulk of the attention, but field stations also had instructions to submit periodic reports and specimens of pathogens and insects that affected various crops, including trees, to the Central Forest Office or to the Imperial Biological-Agricultural Experiment Station at Amani in the Usambara Mts., founded in 1902 (Figure 2-3). Amani's German staff included a director, a chemist, two botanists, a zoologist and a horticulturist supported by several gardeners. Entomology was considered a priority (Schnee 1920). Resident zoologists, at first Prof. Dr. Julius Vosseler, then Dr. Hermann Albert Morstatt (later Prof.), conducted pest inventories and experiments, developed reference collections, ran a laboratory with insectaria, diagnosed and addressed specific problems in various crops including trees, and disseminated results of their work, notably in publications such as "Der Pflanzer" (The Planter) and 'Berichte über Land- und Forstwirtschaft in Deutsch-Ostafrika" (Reports on Agriculture and Forestry in German-East-Africa). They also gave lectures and conducted short courses, such as on the "Principles of Pest Control" (Morstatt 1911a).

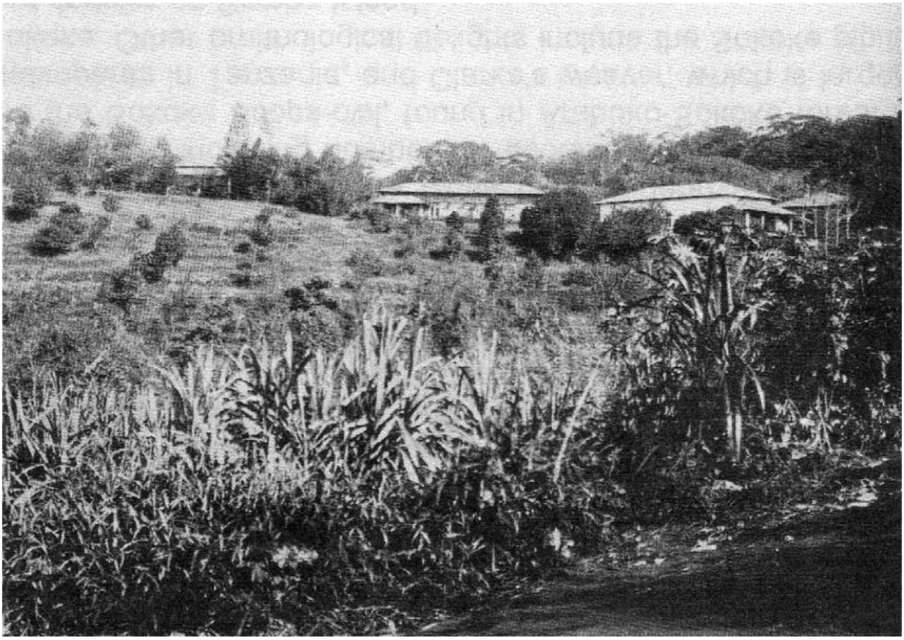


Figure 2-3. The Imperial Biological-Agricultural Experiment Station at Amani in East Usambara, founded in 1902, was the hub of entomological and other research. This station has been playing a major role in the exploration of natural resources on Tanzanian territory to this day. (From Schnee 1920).

Professor Vosseler (Figure 2-4) was the first entomologist to reside in what is now Tanzania (Anon 1931,1947; Lindner 1934). He was born on December 16, 1861 in Stuttgart-Freudental in the German state of Württemberg. After stints as an assistant at the Institute of Zoology of the University of Tübingen and as chief entomologist of the Royal Museum of Natural History in Stuttgart, both in Württemberg, he served from 1903-1908 as resident zoologist at Amani. In 1909 he became director of the famous Zoological Garden Hagenbeck in Hamburg, in which town he died in 1933.

Figure 2-4. Professor Dr. Julius Vosseler, who, from 1903-08, served as resident zoologist at the Imperial Biological-Agricultural Experiment Station at Amani. In addressing aspects of applied entomology, he made many pioneering contributions to the understanding of pest insects in Tanzania. (Reproduced by permission of Staatsarchiv Hamburg).

An analysis of the numerous reports by Vosseler and Morstatt shows that insect pests of primary concern were those affecting a variety of exotic plantation-style tree crops grown either for timber (*Cedrela odorata,* eucalypts and various conifers including pines) or for a variety of non-timber products and services (*Acacia mollissima, Cinchona* spp., citrus crops, *Terminalia catappa, Manihot glaziovii* and various other rubber trees) (Figure 2-5). However, pests associated with certain native tree species *(Cassia* spp, *Cephalosphaera usambarensis, Chlorophora excelsa, Cocos nucifera, Erica arborea, Khaya* spp., *Parinarium holstii*), considered of high quality or of some special interest, were also recorded and sometimes investigated (Morstatt 1913b). While many of these pests had only temporary or local impact, others, including *Tragocephala variegata* Bert. on meliaceous hosts, *Oryctes monoceros* (Ol.) and *Rhynchophorus phoenicis* (F.) on coconut, *Phytolyma* sp. on mvule and various termites on nursery seedlings, rubber trees and young conifers occurred on a recurrent and more serious scale. Swarms of two locusts also occasionally passed through, devastating most vegetation in their path and offering opportunity for extensive studies. Most of the pest reports originated either along the coast or in the nearby Uluguru and Usambara Mts., where many crops were being tested and evaluated or already existed in culture. The zoologists were also responsible for researching tropical, vector-born diseases of humans and livestock, as well as for the promotion of sericulture and apiculture. As Vosseler (1907c) pointed out in an interesting paper on "entomological practice", his work in German East Africa was like learning to

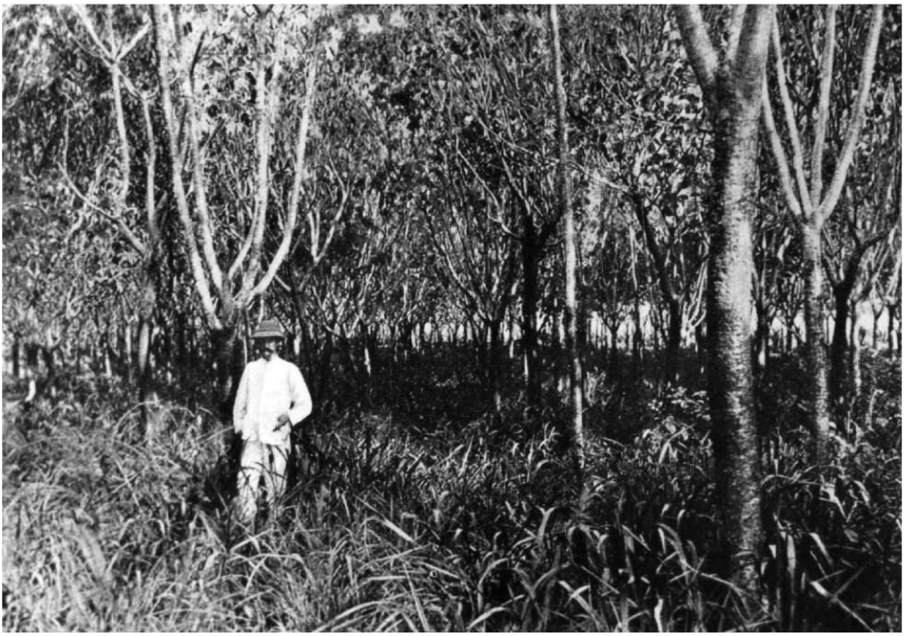


Figure 2-5. A ceara rubber *(Manihot glaziovii)* plantation near Lindi. This was one of the many experimental crops the Germans introduced and researched. (From Meyer 1909).

play a “new, unfamiliar instrument”, a task complicated by numerous conditions inherent in an as yet undeveloped and little known tropical territory. He also complained about much smaller Hawaii being serviced by three entomological organizations with a total of nine scientific staff, while he was the only zoologist responsible for a much larger territory and had much broader assignments. Given these restraints and judging their output, each of the two zoologists did admirable work. Morstatt’s plans to put together a handbook on economically important insects of East Africa unfortunately were derailed by World War I.

During German times, recommendations for prevention and control of pests included a wide array of techniques. Sanitation through local ordinances and delivery of hand-picked specimens for compensation intended to ease problems with rhinoceros beetles, while palm weevils were to be excised from hosts, followed by wound dressing. Growing of mvule under shelter was hypothesized to reduce damage from the very destructive gall psyllids. Trials with an entomopathogenic fungus against migratory locusts were unsuccessful, but, as an appropriate technology, 3-6% soap solutions proved more successful, especially against small insects (Vosseler 1905e, 1908). Termite control involved fumigants on a sulfur or arsenic basis, sugar/calomel bait, kerosene emulsions for bark treatment and the physical destruction of termite queens. The search for naturally durable native woods sought to alleviate structural damage by termites. A historically interesting summary of the most important pests and chemical pesticides of the time, including petroleum, soap, petroleum/soap emulsion, tobacco infusions and arsenates, among others, was provided by Morstatt (1913b, 1914a).

The pragmatic work of in-country scientists was supplemented by occasional scientific expeditions, which had more of a naturalist, zoogeographic and taxonomic focus. In 1905-06, the Swedish Zoological Expedition under Yngve Sjöstedt, anticipating “diverse and unique fauna” especially in the mountains, explored Kilimanjaro and Meru as well as neighboring Maasailand (Sjöstedt 1910). Like Gerstaecker (1873) before him, Sjöstedt considered an “investigation of the insect fauna of the mountain tops of Africa among the most interesting challenges of zoogeography”. The comprehensive harvest of this safari included more than 59,000 specimens, representing 4,300 species, more than 1,400 of which proved new to science. Other travelers and various officials also continued to supply specimens to scientific authorities. Möbius (1898) lists 24 such collectors, who had returned with notable collections of mostly beetles. Even later, after the first crop had yielded a bonanza of new species, collecting continued, with no specific accounting of the players, and only occasional mention of particularly avid contributors, such as W. Janensch. This paleozoologist not only excelled in the excavation of dinosaur bones at Tendaguru, but also managed to put together an impressive entomological collection (Maier 2003).

3. BRITISH COLONIAL PERIOD (1919-1961)

With the advent of a British administration in Tanganyika after World War I under a League of Nations mandate, this protectorate's fate became closely allied with the two British colonies of Kenya and Uganda. For various reasons, however, Tanganyikan development, including forestry, remained low-key compared to that in its northern neighbors. Due to lack of effective enforcement during the transition from German to British rule, forest reserves suffered incursions from locals trying to reclaim what in pre-colonial times had been common property. After the establishment of a Department of Forestry in 1921, the British did, however, begin to reestablish control over the former German forest reserves, and, as a matter of fact, added sizeable new ones, especially in miombo woodlands of the interior. They also continued work with plantations of mostly exotic, but also some indigenous timber species. Any focus on forest protection remained, however, somewhat incidental to work centered in Kenya and Uganda. Some pioneer investigations by W. Wilkinson in the 1920s were limited to forest product pests (Jones and Wilkinson 1965). In the 1930s, W.V. Harris worked as an entomologist for the Department of Agriculture of the Tanganyika Territory, and in the 1940s as senior entomologist for the Department of Agriculture of the Uganda Territory. During his time in Tanganyika he conducted a three-year intensive survey of termites throughout the territory, resulting in major contributions to the understanding of those important insects. In 1934, the three territories of British East Africa agreed to impose identical quarantines on the import of plant materials (Odera and Arap Sang 1980). The East African Plant Quarantine Station was located at Amani in Tanganyika. Concurrent with the focus on timber pests, the then conservator of forests, D. K. S. Grant, conducted two series of trials on the durability of timbers against wood destroyers (Wigg 1946).

Reviving markets after World War II and into the early 1950s resulted in intense forest exploitation (Burgess and Mbwana 2000). F. G. G. Peake's appointment in 1947 as the first full-time forest entomologist in Kenya's Forest Department was largely a consequence of rising concern for the welfare of exotic conifer plantations that had been established in the East African Highlands (Jones 1965a). He is credited with the successful introduction of two biocontrol agents against the eucalyptus weevil, *Gonipterus scutellatus* Gyll. and the Jacaranda blight scale *Insignorthezia insignis* (Browne), respectively. Three years later, J. C. M. Gardner succeeded Peake and in the same year initiated the East African Forest Insect Survey, an undertaking that considerably expanded the scope of forest entomological investigation in East Africa (Gardner 1957a; Jones and Wilkinson 1965; Jones et al. 1965d). For several years the focus was on nursery and plantation pests with continued interest in termite control. In 1958, the Forest Entomology Division of the East African Agricultural and Forestry Research Organization (EAAFRO) was re-established. Between 1957-61, i.e., following Gardner's 1957 retirement, the insect survey he initiated, progressed at a reduced rate. This slowdown was due to higher priority investigations, but the survey again expanded in the mid-60s (Jones and Wilkinson 1965). In these

years, the increasing demand for construction timbers and an acute shortage of building materials resistant to attack by termites and marine borers, made any insects attacking substitute timbers prime candidates for investigation. The East African Forest Insect Survey yielded numerous specimens (Anon 1973), in great part supplied by two full-time African forest insect rangers in each of Uganda and Tanganyika and supplemented by S. J. Curry and J. O. Evans who worked in the Kenya Highlands (Gardner 1957c). The African pioneer para-entomologists, E. Kaye and C. Magola in Uganda, E. Ndekarisho (or E.N. Mshiu?) and N. Ndesamburo in Tanganyika, are credited with having “contributed a great deal of basic information” (Gardner 1956). Many foresters throughout the territory, who had been supplied with insect collecting kits and relevant instructions, also contributed to this effort for years. As a result, more than 1,600 identified specimens were incorporated in the Kenya Forest Entomologist’s central collection at Muguga, Kenya, while a smaller reference series of 470 species became part of the Tanganyikan National Collection at Lushoto (Jones and Wilkinson 1965).

Le Pelley’s (1959) list of agricultural and forest pests in East Africa, together with predators and parasites imported for their control, also reflects the fact that more entomological work was being conducted in the colonies of Kenya and Uganda, than in the Tanganyika Protectorate, and more so with agricultural and veterinary pests than with forest pests. In the late 1950s, the Tanganyikan Department of Agriculture with four research entomologists on staff focused on ticks, tsetse fly and various field crop pests, and also promoted the culture of pyrethrum (*Chrysanthemum (=Tanacetum) cinerariaefolium*), the source of a botanical pesticide. Renewed interest in cocoa and a spectacular increase in the price for cashews resulted in these tree crops also being investigated entomologically (Evans 1960). In the 1950s there were also attempts to promote beekeeping under the leadership of a “beeswax officer” (Smith 1951, 1952, 1957).

Triggered by the emergence of large-scale farming projects and the concurrent worldwide boom in pesticides, a Colonial Insecticides Research Unit (CIRU), born out of tsetse and mosquito control programs, was located first in Uganda, then in Kilosa, and since 1950 at Arusha (Watkins and Walker 1957; Kayumbo 1985). Seven chlorinated hydrocarbons, as well as organophosphates, lead arsenate, and mineral oils were tested on various agricultural and forest pests, including nursery soil, stem and foliage pests, stem and foliage pests of arboreta and ornamental trees, structural and plantation termites, and seed pests. Suitable insecticides were available against these pests, except certain shoot borers. Botanical pesticides, such as pyrethrum, derris and nicotine, despite their drawbacks were still considered viable alternatives. Pyrethrum was commercially grown at Mufindi, Rongai and at West Kilimanjaro and a production factory operated at Mafinga (EN Mshiu, pers. comm.). In 1956, the Agricultural Insecticides Unit at Ilonga, Tanzania was merged with CIRU and given the new name Colonial Pesticides Research Unit (CPRU). Funded by Britain, this unit was administered by the Tanganyikan government until 1962 (Kayumbo 1985).

Many of the insects obtained during the British period, which was strongly focused on woodborers and plantation pests, proved new to science, as determined by taxonomists associated with the Commonwealth Institute of Entomology in the UK. However, many more specimens remained unidentified. The Coryndon Museum in Nairobi housed two large collections of insects from Tanganyika, one from the Amani Biological Research Station, the other built up by Father Conradt, who, as a resident on Ukerewe Island, had collected for many years in the neighborhood of Lake Victoria (Moffett 1958).

Just before his retirement, Gardner (1956) reflected on his years of work as a forest entomologist in East Africa, concluding, that “on the whole, the forest probably suffers little from insects in its natural condition”, but that where “plantations consist of exotics, it is possible that indigenous insects may take to them with enthusiasm”, and that “exotic insects may follow”. This had already happened with the cypress borer *Oemida gahani* Dist. and the eucalyptus weevil *G. scutellatus* Gyll. and subsequently Gardner’s prophesy was to prove true, as pest trends in East Africa, as summarized by Jones (1967) included (a) indigenous insects adopting exotic hosts, (b) the arrival of exotic pests and increased activity of long-established exotic insects and (c) the surge in some native insects such as ambrosia beetles on indigenous hosts.

During the British era, additional new records of many forest and other insects also resulted from various non-governmental expeditions. For instance, W. E. Cutler combined the passion of his predecessor, W. Janensch, for dinosaur bones and insects, while working at the Tendaguru excavations (Maier 2003). A German Zoological East Africa Expedition took place in 1951/52, returning with, among others, 16 species of millipedes, 13 new to science (Kraus 1958). The Belgian IRSAC expedition in 1956/57, which focused on mountain areas of Longido, Oldonyo Sambu, Meru, Kilimanjaro, Same, Kihurio, Korogwe, Handeni, Mziha, the Ulugurus, Makuyuni, Babati, Katesh, Hanang, Ngorongoro and Oldeani, provided another plethora of insects new to science (Basilewsky and Leleup 1960).

4. POST-INDEPENDENCE (1961-1992)

Independence for Tanganyika came in 1961 and political union with Zanzibar was attained two years later, leading to a united Tanzania. This coincided with formation of the East African Forest Protection Service, a unit of the East African Common Services Organization (EACSO) and later of the East African Community (EAC). This Service was headquartered at Muguga, Kenya and employed three pathologists, as well as four entomologists. T. Jones served as deputy director of EAAFRO, as head of the Forest Entomology Division and also as editor for the East African Agricultural and Forestry Journal. He and three other entomologists, W. Wilkinson, Ø. Austarå and K. W. Brown, as well as L. Cole later, conducted inter-territorial insect surveys and research in conjunction with territorial entomologists, including M. J. Reddy, S. C. Prosser, Huber, E. N. Mshiu, and N. Ndesamburo, assisted by

K. Karanja, J. Ngige, J. Kamau, J. Njuguna, H. Kuria and S. Nganga (Jones et al. 1965a,b, c; Austarå and Jones 1971). Special projects remained largely directed at (1) defoliators, shoot borers and termites in nurseries and plantations of native and exotic hard- and softwoods (2) borers affecting standing or felled timber or such in storage or service, but (3) also included surveys, reference collections, the development of host/insect and insect/host indices, as well as taxonomic contributions (Jones and Austarå 1967). Termite research virtually stalled with the departure of Wilkinson (Wilkinson et al. 1965). An investigation into possible means of controlling the mvule psyllid (*Phytolyma*) largely concluded on a downbeat note, as control of this insect by conventional means continued to be elusive. Throughout the 1960s and into the early 1970s, numerous publications resulted, but, based on staff requirements, the forest insect handbook suggested by Jones (1967) never materialized.

In 1962, the Colonial Pesticides Research Unit (CPRU) was also incorporated into the research services of EASCO, and in 1968 absorbed by EAC under the name of Tropical Pesticides Research Institute (TPRI). This institute included the National Herbarium, the Plant Quarantine Station and a third division for pesticide registration and control (Kayumbo 1985). The driving force behind the quarantine service in Tanzania was A. Mushi (T Jones, pers. comm.) During most of the 1960s, an East Africa Specialist Entomological and Insecticides Committee met annually to coordinate research on forest and crop pests. This group also published a list of common names for pest insects and mites in East Africa (Crowe 1967).

In 1968, the exotic pine aphid *Pineus börneri (=P. pini)* (Macquart) surfaced as the first in a string of insect invaders that would in time increasingly complicate plantation forestry in East Africa. The first harbingers of this trend for exotic invaders had been two pathogens in the 1950s: the cypress canker (*Rhynchosphaeria (=Leptentypa) cupressi; F.I. Monochaetia unicornis*) and Dothistroma blight of pines (*Mycosphaerella (=Scirrhia) pini; F. I. Dothistroma pini*). The canker was severe enough to force the replacement of one of the major species of cypress, *Cupressus macrocarpa*, with *C. lusitanica*, and, in a matter of about 20 years, the blight virtually wiped out young plantations of *Pinus radiata* in East Africa (Jones 1965a).

Despite budgetary constraints (previously experienced periodically but a chronic condition starting in the late 60s) some taxonomic work continued into the 1970s, with surveys concentrating on the Usambara Mts. and Ukaguru, as well as the miombo woodlands of Western Province (Jones and Austarå 1967). This work was complemented by a second expedition of the Belgian Royal Museum for Central Africa in 1971 (Berger and Leleup 1971), and one by the Danish Zoological Museum of the University of Copenhagen in 1981 (Scharff et al. 1981). Both took place in the Uluguru Mts. and yielded numerous descriptions of insects new to science, many endemic to this mountain range.

In the early 1970s, a medley of political and economic tensions resulted in the departure of expatriate staff and remaining native staff, E. N. Mshiu and later

E. Z. Kisaka, operated under increasingly difficult conditions (EN Mshiu, pers. comm). With the breakup of the East African Community in 1977, cooperative efforts and communication with Kenya and Uganda ceased. A proposal by the British Center for Overseas Pest Research to develop insect identification services for Africa failed (Sands 1981). In general, forest protection efforts were greatly reduced in both scope and intensity, as reflected in a dearth of publications into the mid-80s.

From 1983 to 1985, sponsored by the Norwegian International Development Agency (NORAD), Prof. Hans G. Schabel, the author of this book, taught silviculture, forest pathology and forest entomology at the Division of Forestry at Sokoine University of Agriculture (SUA) in Morogoro. By that time, the national economy was in shambles and government services were basically defunct. The Tanzania Forest Insect Reference Collection that had been provided by EAAFRO entomologists and housed at the Timber Utilization Unit in Moshi (Anon 1973), had degraded to uselessness, and collections in Kenya were inaccessible because of the closed border. In 1985, new regulations for registration and approval for use of pesticides in Tanzania were enacted.

After Prof. Schabel's return to the University of Wisconsin in the USA, forest entomology at SUA was taught in annual six-week sessions by Drs. A. Bakke and E. Christiansen from the Agricultural University of Norway. In 1994, Dr. Seif Madoffe, who had received advanced training in Norway, accepted a faculty assignment in forest entomology at SUA. From 1998-2000, Dr. Ismail Aloo, with entomological training in Japan, taught forest entomology at the Olmotonyi Forestry Institute, while from 1999-2004, Dr. Innocent Zilihona, with advanced training in Finland, worked as a forest entomologist for the Tanzania Forest Research Institute (TAFORI).

The 1980s brought a revival of traditional agroforestry and introduced scientific study of this alternative land use practice. As a result, Tanzanian forestry expanded its focus to include trees in the context of rural development. A GTZ project addressed various issues concerning the aging coconut groves established during German colonial days that also included investigations into innovative ways of dealing with major coconut pests (Paul 1985). In 1987, the cypress aphid, *Cinara cupressivora* Watson & Vögtlin, arrived in Tanzania, and in 1992 the leucaena psyllid, *Heteropsylla cubana* Crawford, invaded East Africa. This seriously challenged the role of various species of *Cupressus* and *Leucaena*, among the more important plantation trees and woody agroforestry legumes, respectively. Finally, in the late 1980s, a study sponsored by IUCN in East Usambara (Hamilton and Bensted-Smith 1989) signaled an important shift toward assessments of the biologically unique resources of Tanzania.

5. POST-RIO (AFTER 1992)

Following the Rio Earth Summit in 1992, and concurrent with the signing of the Biodiversity Treaty, the international significance of biodiversity was officially ordained, and research funding increased dramatically. In recognition of the fact that

most of the Eastern Arc Mountains (EAM) and Coastal Forests (CF) are contained in Tanzania, this country all of a sudden was the focus of intense interest by biologists (Lovett and Wasser 1993; Depew 1998; Stuart et al. 1990; Burgess and Clarke 2000). The mountains had long been valued for their hydrological significance in this generally dry country, but now attained international prominence as one of the 25 globally recognized biodiversity hotspots. To safeguard Tanzania's unique assemblage of biota, many of them endemic, without compromising legitimate interests of local communities, numerous projects have since been initiated to conduct inventories of various biota and design community-based strategies for Participatory Forest Management and the protection of mountain and coastal forests from destruction by opportunistic land use and pests. In the wake of this new emphasis, and driven by new policies and the "Tanzanian Forest Action Plan" (TFAP) of 1988, forests are now rapidly moving towards the implementation of a sector-wide approach emphasizing the integration of multiple dimensions, i.e., product, environmental and social functions. Since various pathogens (Nsolomo and Venn 1994) and insects may not just be pests, but also critical components of ecosystems, and some play potentially beneficial economic roles, their future study needs to adopt these broader perspectives.

Since both EAM and CF reach beyond the borders of Tanzania, and since exotic pests also have international dimensions, there are now increasing efforts to develop a common nature protection and pest control strategy for the region. This is reflected in FAO's recent coordination of efforts to biologically control the cypress aphid and leucaena psyllid, and in a recent meeting in Malawi of a task force for revitalizing the African Forest Pest Management Network. During this meeting, the Forest Invasive Species Network for Africa (FISNA) was formed. Another relevant and potentially significant agreement, the Global Taxonomy Initiative (GTI) in Africa (Klopper et al. 2002) had already been formulated by the Conference of Parties to the Convention on Biological Diversity (CBD) in 2001. This initiative highlights the prominent taxonomic impediments currently existing in Africa, the fact that vast numbers of specimens of African insects reside in northern collections, and the need for the existing wealth of relevant information to be shared and made accessible to the countries of origin.

While to date taxonomic studies with a focus on biodiversity, biogeography, endemism, or pest status and management have preoccupied most research concerning forest entomology in East Africa, relatively few ecological studies have taken place. One, if not the first, focused on forest soil arthropods in East Usambara and resulted in a key for the most common classes, orders and a few insect families (Jago and Masinde 1968). Another study shed light on the seasonality and structure of an arthropod community in a low valley of the Uluguru Mts. (Nummelin and Nshubemuki 1998), showing that the community structure changed relatively little during one year and that eight groups made up over 95% of all specimens caught, that arthropod numbers peaked during the late rainy season and early dry season (May to August), and that the abundance of Diptera, Hymenoptera and Hemiptera

increased with rain. In a recent canopy fogging study, apparently the first in Africa, altitudinal patterns of homopteran species richness and composition in comparison to that of a plant community in East Usambara were investigated (McKamey 1999). Finally, arthropod diversity and abundance were evaluated along the Kihansi Gorge in the southern Udzungwa Mts., documenting the highest diversity in the forest spray zone, where also the rarest orders were found (Zilihona et al. 1998; Zilihona and Nummelin 1999, 2001).

CHAPTER 3

DEFOLIATING INSECTS

1. INTRODUCTION

In the temperate zones, many insects relying on tree foliage for food are among the most notorious of forest pests. Despite the fact that foliage of tropical trees contains defensive substances (polyphenols) and tends to be nutritionally poor, except in nitrogen-fixing trees that have higher levels of foliar nitrogen (Speight and Wylie 2001), there are numerous tree defoliators in East Africa. Not all use foliage directly for food. A few rather use it as a medium for the cultivation of food fungi, and occasionally leaf parts may be serving in the construction of nests. Most defoliators thrive on healthy hosts. While few tropical defoliators have precise host dependencies (monophagy), most attack several (oligophagy) or numerous tree species (polyphagy), usually selecting a range of species in related genera or families. The low host specificity of tropical herbivores in general is used as an argument against overestimates of arthropod diversity (Novotny et al. 2002).

1.1. Types of Defoliation

Specific feeding guilds attack foliage in different patterns. A major distinction can be made between those insects feeding on foliage internally (miners) and others that feed on foliage externally (browsers or free feeders). Many sap feeders and gall insects also attack foliage, but employ a different mode of attack and are not necessarily restricted to foliage. As a result, they are discussed in chapter 4.

1.1.1. Leaf Miners

These small insects live inside foliage and consume only the green parts while sparing the epidermal layers. Their activity becomes visible in characteristic serpentine or patchy discolorations on the leaf surface.

1.1.2. Free Feeders

The browsers attack foliage from the outside in characteristic ways. Window feeders consume leaf tissues from one side of the leaf only without breaking the epidermis

on the other side, leaving a thin pane. Others, called skeletonizers, completely devour only the soft parts of foliage and leave a lattice of veins. Large browsers consume irregular chunks of foliage often including veins, either feeding from the margin or excising holes in the middle of the leaf blade. Leaf cutter bees are more systematic by removing semi-circular portions from the leaf margin with almost surgical precision. They use these for nest construction rather than as food. Some defoliators, called leaf rollers, leaf tiers, leaf folders, web spinners and bagworms, employ silk to build characteristic leaf shelters to live in.

1.2. Impact of Defoliation

Defoliation for a tree is similar to stomach problems in animals; it interferes with food production and processing. Depending on a number of factors, including species of tree, severity, season and frequency of defoliation, this event may cause differing degrees of growth loss, but may also directly or indirectly, through the involvement of secondary stress agents, lead to mortality. Normally, defoliators do not consume more than 10 % of annual leaf production (Dajoz 2000), and less than 20% defoliation will generally have little effect on tree hosts (Speight and Wylie 2001).

In the 1960s, defoliators were, however, considered to be a major threat to exotic tree plantations in East Africa as indigenous insects adapted more easily and frequently to a diet of exotics. In pines, in particular, outbreaks occurred with some regularity (Jones and Austarå 1967). As a result, these insects became the focus of a special research program of the Forest Entomology Division, while a watching brief was kept on termites and borers. It was found, that complete artificial defoliation of 3-year old *P. patula* in East Africa did cause a 50 % reduction in growth, but no mortality, the loss considered economically tolerable at the time (Austarå 1968, 1970). Similar experiments in Zambia with *P. kesiya* and *P. oocarpa* did not cause mortality either, and growth reductions were only on the order of 15 to 30% (Löyttyniemi 1981). The good survival and resilience of tropical plantation pines, also observed elsewhere, was attributed to their nearly continuous growth year round, which quickly replaced the foliage lost to defoliation. Another major reason defoliation of trees is often tolerable in East Africa, is the fact that natural controls (Figure 3-1) rarely allow populations of defoliators to retain outbreak levels for longer than weeks or months.

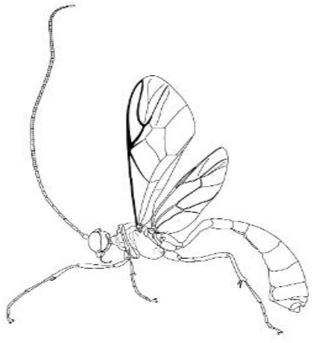


Figure 3-1. Ichneumonid wasps (Ichneumonidae), such as this specimen from Mpwapwa (mid-March), together with other parasites play significant regulatory functions in the population dynamics of defoliators. (P. Schroud).

Since quite a number of defoliators happen to be edible, while others produce silk or are sought as collectibles, there are frequently beneficial dimensions to defoliators, as discussed in Chapter 9.

1.3. Defoliating Orders

By far the most significant defoliators in East Africa are Lepidoptera, followed by some Saltatoria and Coleoptera. In other parts of the world, sawflies (Hymenoptera) are serious defoliators, but only few species are known from East Africa, and none has been implicated in notable tree damage. The aforementioned leaf cutter bees (Megachilidae) are also insignificant as pests. East African defoliators are mostly indigenous insects attacking indigenous trees, but certain species habitually take to exotic tree hosts and have even developed a preference for them. To date, only one exotic defoliator, the eucalyptus weevil, *G. scutellatus,* has taken hold in East Africa, but this beetle is restricted to exotic eucalypts.

Best known among numerous defoliators in East Africa are 63 species of indigenous Lepidoptera attacking exotic softwoods, mostly pines and cypresses. These are listed, together with hosts and distributional records, by Austarå and Jones (1971). However, only a few have caused serious or complete defoliation of certain plantations. Outbreaks were remarkably short-lived as natural controls usually took effect (Gardner 1956; Robertson 1973).

As with Lepidoptera, concern with defoliating Coleoptera and Saltatoria is greatest in conjunction with exotic plantation species or agroforestry crops. Locusts continue to have at least the potential for occasional disastrous impacts on various crops, including trees.

2. DEFOLIATING BEETLES (COLEOPTERA)

2.1. Chrysomelidae: Leaf or Flea Beetles

This huge family of some 37,000 species worldwide, consists of small to middle-sized beetles of great diversity. The fact that Gerstaecker (1873) described 40 new species of leaf beetles from Tanzania alone indicates the great diversity of this beetle family in this country.

In some species, both larvae and adults are external defoliators of plants, including trees. In others, the larvae mine leaves or bore in stems, seeds and roots. Certain species are ant mimics that live in association with cocktail ants in pseudo-galls on *Acacia drepanolobium*. For many of the tropical species, hosts are still unknown. Some of the larvae of South African chrysomelids serve as a source for a powerful arrow poison employed by bushmen, and in other parts of the world, some of the more host-specific leaf beetles have become useful as biocontrol agents against invasive weeds.

2.1.1. Description

Leaf beetles are highly diverse in shape and color. Adults often sport bright, metallic patterns. Some resemble ladybird beetles (Coccinellidae) in shape, size and coloration, but have four as opposed to three tarsal segments. One group called flea beetles has enlarged hind femora allowing them to jump. Another group, the tortoise beetles, also aptly named, resemble mini-turtles. Larvae are equally versatile, including some that are camouflaged under a protective case made of their own feces. Pupae are usually attached head-down on the food plants, another habit they share with ladybird beetles.

2.1.2. Miscellaneous Leaf Beetles

While quite a number of chrysomelids are important agricultural pests (Le Pelley 1959), none of the tree defoliators observed to date in East Africa have been significant. In German days, there were some small-scale outbreaks with three species (Aulmann 1911). This included *Ceralces ferrugineus* Gerst. and *Oïdes collaris* Baly, both defoliators of *Manihot glaziovii*. The first, a smooth, somewhat glossy, 8-10 mm long rusty red beetle with black appendages, is widely distributed in East Africa and southward. *O. collaris* is about 11 mm long, with a black head and antennae and strongly convex elytra (Figure 3-2). The third species, *Malacosoma gracilicorne* Wse., is a common defoliator of *Crotalaria* in East Usambara during October. This beetle is 6 mm long and mostly dark blue and black. The elytra are a metallic bluish-green with long, grey setae. At another time, an unnamed flea beetle occasionally attacked the foliage of kapok, but was only dangerous to young trees (Harris1938). *Chrysomela* (=*Melasoma) keniae* Bryant defoliated *Populus* in Kenya, while larvae and adults of *Megaleruca triloba* F. caused heavy defoliation of *Trema guineense* at Lushoto, as well as other parts of East Africa (Gardner 1957a). This 7 mm long beetle took about one month to develop and estivated for months. *Phaedonia areata* F. was reported from *Indigofera, Exora* spp. from *Ocotea usambarensis,* and *Megalognatha lamaticornis* Lab. from eucalytps in Tanzania (Le Pelley 1959). A recent report from Zimbabwe emphasized the fact that *Chrysomela* (=*Melasoma) quadrilineata,* a defoliator of *Brachystegia spiciformis,* maintained outbreak conditions over two consecutive seasons (Reeler et al. 1991).

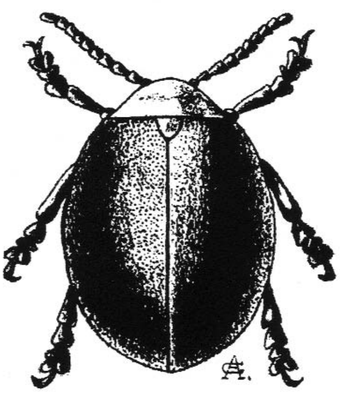


Figure 3-2. This leaf beetle, *Oïdes collaris,* a defoliator of ceara rubber trees, *Manihot glaziovii,* exhibits the typical shape of most Chrysomelidae. (From Aulmann 1911).

Lately, there have been reports of increasing damage by chrysomelids in agroforestry. For instance, in Ethiopia a beetle tentatively identified as “*Calliandra* leaf beetle”, in a very heavy infestation with often more than 100 beetles per branch, completely defoliated saplings of *Calliandra calothyrsus* and *Leucaena leucocephala*

(Bekele 1993). This is an elongate bluish green or bluish brown beetle of variable size with long antennae and the pronotum narrower than the elytra. Other leaf beetles, *Mesoplatys ochroptera* Stål, occurring throughout East Africa, and *Exosoma* sp. were reported as abundant pests of *Sesbania* and some leguminous trees in Malawi and other parts of southern central Africa (Mchowa and Ngugi 1994; Rao et al. 2000). Also in recent years, *Crotalaria* in planted fallows in western Kenya were frequently and seriously defoliated by *Amphicalia pectolina* (Chrysomelidae?). It seems likely that in the future more woody plants, especially legumes in agroforestry, may experience damage levels requiring attention.

2.2. Curculionidae: Weevils, Snout Beetles

With an estimated 50,000 species, the weevils represent worldwide the largest beetle family. Gerstaecker (1873) and Marshall (1944) noted the particular wealth of weevils in Eastern Africa, but, with few exceptions, relatively little detail is known about the forest weevils. Records often exhaust themselves with lists of names in association with hosts, such as those by Gardner 1957a, who lists five pages of weevils and Le Pelley (1959), who enumerates additional weevils from various tree species in East Africa. These records often were obtained in conjunction with commercial tree crops such as black wattle, pine, cypress and eucalypts, when even nibbles were considered noteworthy.

All weevils are plant feeders, and numerous species are pests in agriculture, horticulture and forestry in different parts of the world. Their habits vary greatly. Various weevils attack tree foliage, buds, shoots, bark, wood (living, declining and dead), roots, fruit or seed, mostly as borers of one kind or other. Some are space parasites in the galleries of ambrosia beetles. In some species only the larvae are tree pests, while in others only the adult or both stages are.

2.2.1. Description

Weevils are sturdy, small to middle-sized beetles. Most are drab brown to black or grey. The single most conspicuous characteristic is an elongation of the head into a beak or snout (proboscis) that carries typical, but tiny chewing mouthparts at the tip. Antennae are elbowed and clubbed. Many adult weevils are often long-lived.

2.2.2. Tree Defoliating Weevils

Dicasticus gerstaeckeri Faust: This weevil was a common defoliator of many species of wild shrubs and most crops in the eastern Usambaras (Morstatt 1912a,e). Occasionally, outbreaks of this beetle affected commercial tree crops such as coffee and *Cinnamomum camphora*. The related *D. affinis* Hartm. feeds on the foliage of eucalypts in Tanzania.

D. gerstaeckeri adults (Figure 3-3) are 11-15 mm long and have a short, broad proboscis (Morstatt 1912a,e). They are densely covered with metallic green to blue scales. Flat batches of 30-50 white eggs (1mm) are laid between two leaves stuck together or into dry, rolled-up leaves. The white, hairy larvae hatch shortly afterwards. Some adults live as long as 18 months.

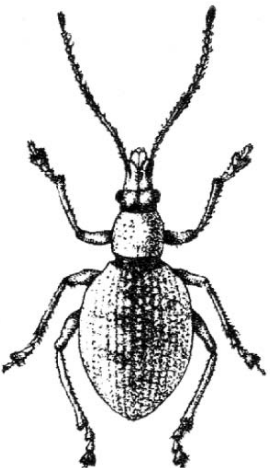


Figure 3-3. Dicasticus gerstaeckeri (Curculionidae), one of the better-known coleopterous tree defoliators in Tanzania. (From Morstatt 1912e).

This beetle is easily collected because it drops when host plants are beaten or shaken in the morning hours.

Gonipterus scutellatus Gyll.: The eucalyptus or gum tree weevil originated in Australia, where it is an uncommon insect and relatively minor pest. However, it became a pest of considerable importance, after being accidentally imported to New Zealand, the Americas and the Mediterranean. In 1916 it was detected in South Africa and subsequently spread rapidly northward (Mossop 1929). The weevil reached Malawi and Mozambique in the 1930s, was observed defoliating *Eucalyptus globulus* on thousands of acres in Kenya in 1944, and shortly afterwards was also documented in Uganda (Kevan 1946). As this insect had by then not been reported from Zimbabwe and from Tanzania, the northernmost extensions of the weevil in Africa may have resulted from independent introductions, rather than from spread. The weevil is restricted to eucalypts but has also been observed to attack apple trees in its original range. In East Africa, the most susceptible hosts include *E. globulus*, *E. maideni*, *E. robusta* and *E. smithii*. Some eucalypts appear to be less susceptible or are entirely immune, such as *E. saligna* and *E. citriodora*, respectively (Gardner 1957a; Griffith and Howland 1962).

Larvae and adults of this weevil cause considerable damage to coppice shoots and foliage on trees of any age. The beetles feed mostly along the edges of the leaves, giving them a scalloped appearance and young growth may be almost denuded of leaves. They also gnaw the bark of young shoots, giving them a pitted look and often girdle them completely. Damage by the larvae is considered more serious, as leaves are eaten almost completely, except for the hard fibers that turn brown and dry. As a result, the first sign of attack are treetops that appear scorched. Defoliated trees often produce epicormic shoots that are also subject to attack, before becoming stunted, showing dieback and dying.

The eggs are laid on very young leaves or shoots in batches of 5-13, averaging nine at a time, and more than 250 in a lifetime of about six months (Esbjerg 1976).

They are covered with a hard, rough capsule of feces (Figure 3-4) that is initially black before turning sepia-brown later. This cover is about 3 mm in length and slightly less in width. The yellow eggs are less than 1 mm long. In Kenya, eggs take about 10 days to hatch and the young grubs eat their way through the leaf beneath the egg capsule (Kevan 1946). As a result, the capsules appear intact after the larvae have left.

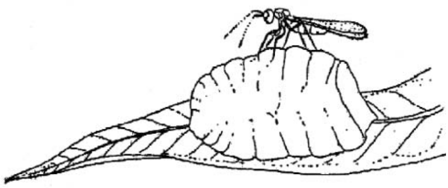


Figure 3-4. The parasitic wasp *Anaphes nitens* (Chalcidoidea: Mymaridae) searching for oviposition site on an egg capsule of the eucalyptus weevil, *Gonipterus scutellatus (Curculionidae).* (From Mossop 1929).

The larva, a legless grub, is slug-like, bright yellow-green, with a dark lateral stripe on each side and studded with small black dots. Fully grown it is about 6 mm long and sticky to the touch. The feces of the larva characteristically form a long, black curling pipe that remains attached to it for a considerable time. The grubs eat narrow slits in the epidermis of leaves and after some weeks drop from the trees to pupate 3-10 cm deep in the litter.

The pupa stage lasts about a month, after which the adults (Figure 3-5) emerge to attack trees, mate and lay eggs. They are strong fliers and mate repeatedly. The weevil is about 6-8.5 mm long, half as wide and has a blunt beak. It is distinguished by a light reddish-brown or grayish-brown powdery bloom and characteristic X-shaped mark across its front wings, which may become less pronounced as scales are lost with advancing age. In Kenya the beetles probably breed continuously with peaks of activity differing based on locality.

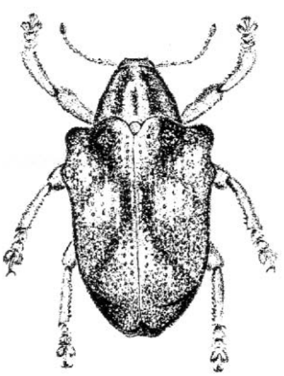


Figure 3-5. The eucalyptus weevil *Gonipterus scutellatus* (Curculionidae). (From Booth et al. 1990; reproduced by permission of CABI Publishing).

Given favorable experiences gained in New Zealand and South Africa (Mossop 1929), the most feasible control appeared to be biological. As a result, several consignments of the egg parasite *Anaphes nitens* (Gir.) (Hym: Chalcidoidea, Mymaridae) were introduced in Kenya in 1945 (Figure 3-4) and also in Dodoma in the 1970s (Massawe 1993). This wasp oviposits directly through the weevil's egg capsule or from below through the leaf into the eggs. Larval development and pupation take place inside the egg. Hatched wasps chew their way through the egg capsule. Unlike many other Chalcidoidea, this wasp reproduces sexually and eggs are laid the same day that mating takes place. Development from egg to adult takes 2-4 weeks (Mossop 1929). Aided by wind, the wasp quickly became established and brought the weevil under control (Kevan 1946; Curry 1965a), although not to the same degree everywhere (Gardner 1957a).

To supplement the parasite, the planting of susceptible eucalypts was discontinued (Curry, 1965a).

Systates spp.*: Systates Weevils.* There are at least six species of *Systates* in East Africa (Gerstaecker 1873; Marshall 1944; Le Pelley 1959), with some confusion among names. Most often mentioned are *S. crenatipennis* Fmre., *S. surdus* Mshl., *S. pollinosus* Gerst. and *S. (= Nematocerus) castaneipennis* Hustache. The adult weevils are usually minor pests on many species of plants, including agricultural crops and trees such as acacias, *Cassia*, citrus, eucalypts, *Markhamia platycalyx*, *Cinnamomum camphora* and rubber trees (Aulman 1911; Morstatt 1912a; Gardner 1957a; Le Pelley 1959; Booth et al. 1990). *S. pollinosus* and *S. surdus* are considered minor pests of *P. radiata* in Kenya. Slight attacks on young pines have also occasionally been observed in Malawi (Esbjerg 1976).

S. pollinosus weevils (Figure 3-6) are 7.5-12 mm long, the male smaller than the female (Booth et al. 1990). The front wings of all species of *Systates* are marked by ten rows of deep pits. The beetles are black or dark brown and, in fresh specimens, whose white or pale brown scales are still intact, appear dusted. The antennae are slightly longer than half the body length (Booth et al. 1990). Eggs of *Systates* are laid on leaves and the larvae apparently live in soil (Gardner 1957a).

Miscellaneous Other Defoliating Weevils. The adults of several other species were also listed as tree defoliators, their larvae suspected of living in soil, perhaps on the roots of herbaceous hosts (Gardner 1957a). *Entypotrachelus meyeri* Klbe. is a very common defoliator of numerous species of trees in nurseries and plantations, including *Acacia melanoxylon, A. mollissima*, *Cassia didmyobotrya*, *Cinnamomum camphora*, as well as *Eucalyptus citriodora*, *E. medinae* and *E. viminalis*, while *E. maideni* and *E. resinifera* are immune. *Opseodes piger* Mshl. is a serious defoliator of many young forest trees and various food crops, including *Chlorophora* in East Africa (Gardner 1957a). Damage occurs in May. *Cychrotonus marginalis* Fst. defoliates *Afzelia quanzensis* and young *E. citriodora* in Tanzania, while *Opseotrophus sufflatus* Fst. and *Peribrotus pustulosus* Gerst. attack various eucalypts (Gardner 1957a). *Epipedosoma undulates* Mshl. defoliated cypress in Tanzania.

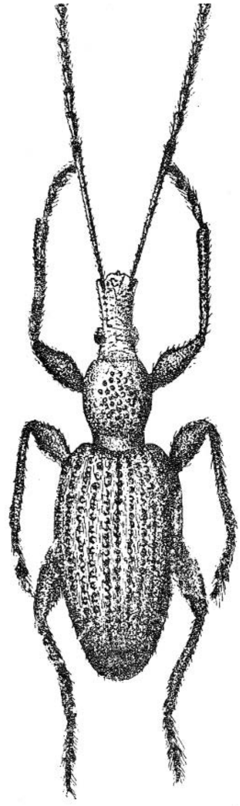


Figure 3-6. Systates pollinosus (Curculionidae), a common but minor pest of many crops and trees, including pines. (From Morstatt 1912e).

2.3. Attelabidae: Leaf-rolling Weevils

Some taxonomists consider these beetles a subfamily (Attelabinae) of the weevils. They are generally more conspicuous than economically important. Females build characteristic, artful leaf rolls in which they lay their eggs (Figure 3-7). One Australian species developed as a minor pest of eucalypts in South Africa (Diabangouaya and Gillon 2001).

Figure 3-7. Each of the characteristic leaf rolls constructed by a leaf-rolling weevil (Attelabidae) contains several eggs or larvae.

2.4. Lagriidae: Long-jointed Beetles

This is a mostly tropical family of over 1,000 species, but very little is known about East African representatives. One species, *Lagria villosa* (Figure 3-8), was reported as a very damaging defoliator of ceara rubber trees, both in larval and adult stages (Morstatt 1912c). They also caused sufficient bark damage to kill young trees.

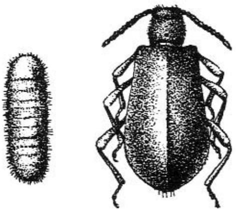


Figure 3-8. Larva and adult of *Lagria villosa* (Lagriidae), very damaging defoliators of ceara rubber trees, *Manihot glaziovii.* (From Morstatt 1912c).

3. DEFOLIATING CATERPILLARS (LEPIDOPTERA)

3.1. Geometridae: Loopers, Cankerworms or Inchworms

This very large family of about 20,000 species of small to middle-sized moths, includes some serious forest pests in parts of the world. During his expedition at Meru and Kilimanjaro, Sjöstedt (1910) noticed that while ordinary Lepidoptera prevailed up to about 1,200 m, that "higher up and especially at the upper limit of the cloud forest…a quite different, until now almost unknown lepidopterous fauna…especially rich in geometrids…" occurred.

Loopers are unique in that in addition to the standard three pairs of thoracic legs they have a pair of fleshy legs each on the 6th and 10th abdominal segments. This gives them an odd, looping mode of locomotion that accounts for their common

name loopers. They extend the anterior part of the body forward, anchor the thoracic legs there, then pull up their posterior until the abdominal legs are positioned right behind the thoracic legs. The moths have relatively large, delicate wings and a slender, equally delicate body. The wings are held either vertically over the back, or in a flat, half- to fully open fashion. In many species both stages are masters of camouflage. Color, shape and immobility during the day make them blend with foliage, bark, wooden spurs and lichen.

A number of loopers were reported as forest pests on exotic conifers and hardwoods in East Africa (Gardner 1957a; Brown 1962; Curry 1965a; Esbjerg 1976), but *Xanthisthisa tarsispina* Warr. received special attention because it defoliated *Cupressus lusitanica*, various pines and *Podocarpus* spp. at Amani, Bukoba, Njombe, Iringa, Mbeya and Sao Hill (Austarå 1968; Austarå and Jones 1971). This moth (Figure 3-9) is light brown with numerous small black specks and strongly marked brown lines across the wings and along the edges. It has a wingspan of about 35 mm. In Malawi, where defoliation by this insect was most severe, a virus brought this looper under control (Esbjerg 1976).

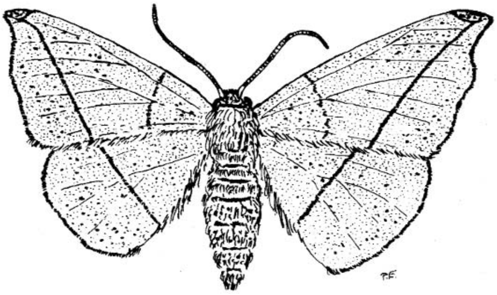


Figure 3-9. Xanthisthisa tarsispina (Geometridae) female, an occasionally severe defoliator of conifers. (From Esbjerg 1976; reproduced by permission of P. Esbjerg).

3.2. Hyponomeutidae

Caterpillars of *Hyponomeuta morbillosa* Z. are defoliators of *Elaeodendron* in East Africa. In Kenya they defoliated entire trees, completely enshrouding them in whitish webbing (Gardner 1957a). The pupae are found in thick mats at the base of trees. In July, a tachinid fly parasitized 30% of these insects.

3.3. Lasiocampidae: Lappet caterpillars, Eggar moths

These are medium to large, stout-bodied, very hairy, usually brown moths. When at rest, the hind wings often show partially as they protrude from under the front wings. Eggs are generally arranged spiraling around twigs (Skaife 1979). The caterpillars often have lateral tufts of hair or flanges called lappets. These are held tight against the substrate, making the insect blend perfectly against bark (Figure 3-10). The silken cocoons, attached to twigs of the host, often incorporate host leaves. Despite urticating hairs, the cocoons are a potential source of wild silk as detailed in chapter 9. They have also been traditionally used for bracelets, anklets and rattles. Pupae and

caterpillars of certain species are used for food.

A number of lasiocampids are defoliators of hardwoods and/or conifers in East Africa (Gardner 1957a; Le Pelley 1959; Austarå and Jones 1971; Esbjerg 1976). Acacias are the most frequent hosts for this family, but exotic hardwoods and conifers account for most of the economic concern. At least eight pest species exist in Tanzania, but with a few exceptions, little is known about their biology. Fortunately, native parasites seem effective at curbing these insects (Figure 3-11).

3.3.1. Lechriolepis basirufa Strand. Caterpillars of this moth feed on a number of hardwoods, including eucalypts, *Acacia mearnsii*, *Maerua triphylla*, *Schinus molle* and *Syzygium guineense*. They have caused some concern as locally serious defoliators of *Pinus patula* and

Figure 3-10. Dorsal view of a well-camouflaged lappet moth (Lasiocampidae) caterpillar blending in with the bark of a miombo tree.

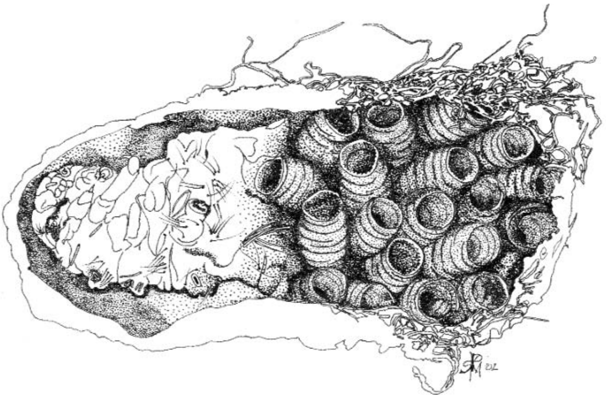


Figure 3-11. The opened cocoon of a Lasiocampid moth showing remnants of a caterpillar (left) and 19 hatched puparia of a tachinid endoparasite (Dip: Tachinidae). Collected mid-January on *Acacia mellifera* at Kitumbeine. These flies, together with hymenopterous parasites and viruses, frequently account for outbreaks of lepidopterous defoliators to be of short duration. (P. Schroud).

P. radiata in various highlands of Kenya and at Moshi and Sao Hill in Tanzania (Austarå and Jones 1971).

When a quick-acting nuclear polyhedrosis virus was observed to cause significant mortality of larvae in the field, the potential of this pathogen for microbial control of *L. basirufa* was assessed (Austarå 1969a). This defoliator also served as an "incubator" for the braconid wasp *Apanteles trilineatus* Cam., to be used as a potential biocontrol agent (Mshiu 1971).

3.3.2. Gonometa podocarpi Aur.

The genus *Gonometa* is widespread on the continent, with at least five species in East Africa (Le Pelley 1959). Best known is *G. podocarpi*, a species restricted to the East African Highlands (Austarå 1971). The caterpillars of this large moth are defoliators of various native and exotic conifers and hardwoods (Gardner 1957a; Austarå and Jones 1971; Mshiu 1971). At one time known to cause only slight damage to acacias, *Podocarpus* spp., *Juniperus procera*, and *Myrica kilimanjarica*, caterpillars of this moth were in 1950 for the first time reported as defoliating *Cupressus* spp. in Uganda and Kenya. They were subsequently also found on other exotics such as *Acacia mearnsii*, *Eucalyptus paniculata* and various pines. While infestations in Kenya and at Mbeya, Njombe and Sao Hill in Tanzania were judged as considerable, serious outbreaks were experienced in Uganda (Austarå 1971; Mshiu 1971). In Kenya, this moth and *L. basirufa* are still considered potentially serious pests of softwood plantations (Nyamai 1996). As determined in Uganda, densities of 1-2 advanced instars of the caterpillars per meter branch are considered necessary to cause complete defoliation (Austarå 1971).

Advanced instar caterpillars are up to 90 mm long and thick as a thumb (Gardner 1957a). Densely covered with long, yellow hairs, all segments bear many long, sharp spiny, urticating hairs, which are black to metallic-violet on the abdominal segments and reddish-brown with dark tips on the thorax. Depending on the abundance of the spines, the general color pattern of the larvae varies from uniformly yellow to patchy black mixed with yellow. The thorax is from red/brown and black to almost pure yellow.

The cocoons are 17-30 mm wide and 40-75 mm long. They are oval to cylindrical and from whitish, grayish to brownish. Made of a tough, parchment-like silk, they are protected by spiny larval hairs, giving them a hedgehog appearance. Usually attached to twigs or needles, they are also found on undergrowth.

The adult moths (Figure 3-12) vary in size, the wingspans of females reaching 112 mm, those of males only 70 mm. The body of both is densely covered with red-brown hair above and yellowish-brown hair underneath. The front wings of females are brown with a faint violet sheen and four darker brown transverse bands. Hind wings are uniformly brown with a slightly translucent middle. Both wings of males are a uniform dark red/brown on both sides and devoid of markings. The anal hair tuft is orange.

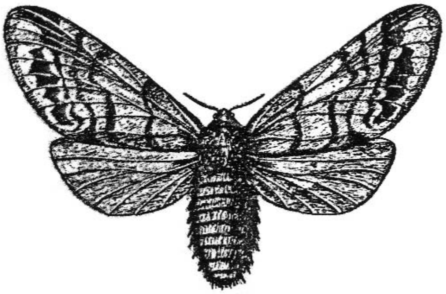


Figure 3-12. Gonometa podocarpi (Lasiocampidae) female. (From Reisch 1961; reproduced by permission of Springer Science and Business Media).

The development of this moth was studied in great detail in pine plantations in Uganda and to some extent at Mufindi, Tanzania. In Uganda two generations were reported (Austarå 1971). In Tanzania there appears to be only one generation, which takes about nine months from egg to the adult stage (Mshiu 1971).

Within one day of emergence, females mate and lay white, spherical eggs about 2.5 mm in diameter. The eggs are glued in batches of about eight on needles or bark near the tips of pine branches, for a total of up to 54 in a day. Aging eggs turn dark grey. The total number of eggs per female averaged 244 in Uganda, where they were present from early April to mid-July, and early October to early January.

In Uganda, average incubation time was 25.5 days, while caterpillars hatched after one and a half months at Mufindi. There were normally 6-7 instars, but even eight were reported in Uganda. At Mufindi, every instar could be found throughout the year, but larvae were most abundant from October to March.

Last instar larvae spun cocoons, the peak of pupation at Mufindi coinciding with August-September. In Uganda, the larval generations started developing near the end of one rainy season and reaching the later instars during the dry season and at the onset of the following rains. Cocoons occurred between mid-February and the first half of June and between the latter half of August and the end of November. The pupa stage lasted a minimum of 33 days and a maximum of 81 days in Uganda, averaging between 35-54 days.

At Mufindi, moths hatched after one and a half months. They were found throughout the year but their peak occurrence was in October. At Muko in Uganda, there were two flight periods a year, one during April to June, the second from October to December, coinciding with the peak of rains (Austarå 1971). The average longevity of males in Uganda was eight days and 10 days for females.

A virus (Harrap et al. 1966) and various parasites were found in association with *G. podocarpi*, at times giving a good degree of control (Austarå 1971). Larvae were attacked by the tachinid *Palexorista (=Sturmia) gilvoides* Curr. (Reisch 1961, Austarå 1971), containing an average of 28 puparia of the parasite. There was also a less specialized parasitic ichneumonid wasp, *Pimpla mahalensis* Grib. (Gardner 1957a). Another parasitic wasp, the braconid *Apanteles trilineatus* was reared and released for biological control of these moths (Mshiu 1971, 1976).

3.3.3. Miscellaneous Other Lasiocampids

A close relative of *G. podocarpi*, *G. postica* Wlk. is found throughout the subcontinent, including Tanzania (Strand 1913). This caterpillar is considered largely beneficial as it feeds mostly on weedy *Prosopis* (Scholtz and Holm 1985), and only to a lesser extent on *Acacia mearnsii*. In South Africa the caterpillars are considered edible and are presently investigated for their sericultural potential.

For other lasiocampids in Tanzania, little more than a few hosts are known (Gardner 1957a; Le Pelley 1959; Austarå and Jones 1971). *Diapalpus congregarius* Strand feeds on acacias, fig trees and *Brachystegia*; *Anadiasa* spp. feed on *A. mearnsii* and *Grevillea robusta*, while *Chilena bettoni* Aur. prefer *A. mollissima*; *Schausinnia affinis* Aur. is a defoliator of pines and cypresses, *Nuxia congesta*, *Rhus* and *Vernonia holstii* at Msiwasi; *Streblote cuneatum* Dist. and *S. diplocyma* Hamps. were minor defoliators of many plants including exotic hardwoods and conifers at Kawetire, Njombe and Sao Hill (Austarå and Jones 1971). In the mid-80s, small-scale outbreaks of *Trabala* sp., a defoliator of *Terminalia catappa*, occurring on the Campus of Sokoine University of Agriculture, were set back annually by parasites, including a braconid wasp (Figure 3-13).

3.4. Lymantriidae (=Liparidae): Tussock Moths

Despite the fact that African lymantriids are represented with 91 African genera (Collenette 1955), relatively little beyond hosts is known about most species. Le Pelley (1959) includes a long list for East Africa, especially Uganda, but only very few from trees in Tanzania. In Morogoro alone, 12 species of tussock moths were reported by Dall'asta (1975) and one more by Schabel et al. (1988). Some species of tussock moths are highly significant forest pests in the northern hemisphere.

This is a family of medium-sized, drab-colored or whitish moths. In some species, females have non-functional wings or none at all, while males are good fliers and have large antennae. Caterpillars are hairy and often have dorsal glands on the 7th and/or 8th abdominal segment. In the most typical kind, the hairs are bundled in short brush tufts and longer pencil tufts, accounting for the name tussock moths.

*3.4.1. Heteronygmia (*syn. *Lymantria) dissimilis* Aur.*: African Mahogany Defoliating Caterpillars*

Among the few defoliators known to target *Khaya* spp. in Africa (Ballard 1914), only this apparently monophagous species appears to have pest potential as indicated by small-scale outbreaks observed in Morogoro, Tanzania in the 1980s (Schabel et al. 1988). This moth was first described as a new species from Mombo (Sjöstedt 1910) and also occurs at Moshi.

At Morogoro, a succession of four generations per year allows *H. dissimilis* to be active most of the year, except for a period of estivation during the hottest season

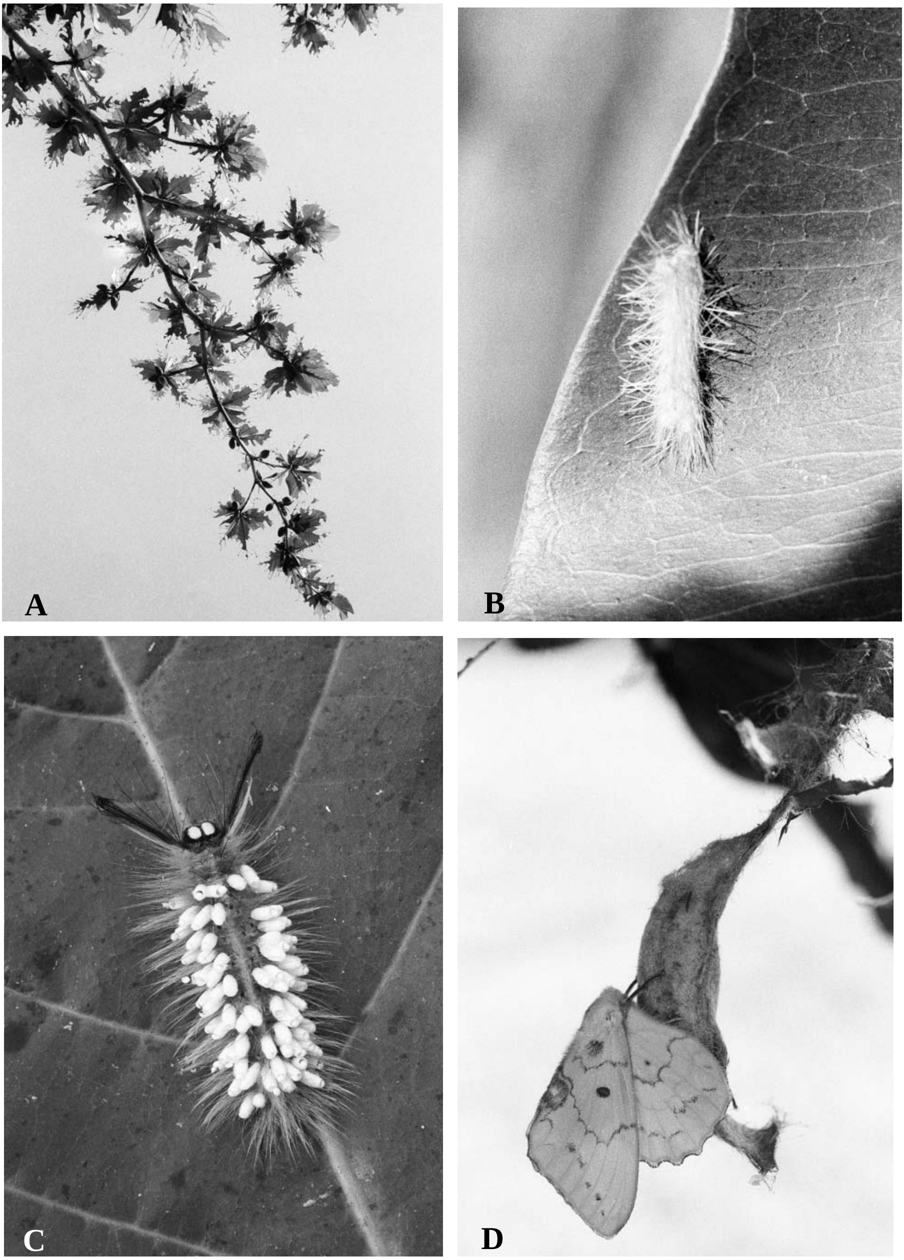


Figure 3-13. Trabala sp. (Lasiocampidae). (A) Damage caused by this defoliator of *Terminalia catappa*. (B) Egg cluster (C) Mummified caterpillar with numerous cocoons of a braconid endoparasite (Hym: Braconidae), and (D) Female moth sitting on the cocoon she hatched from. Her display of the hind wings is characteristic for many lappet moths.

from November to February. Eggs (Figure 3-14A) are found from early March to late October with peaks from May to August, during the cool, dry season. Egg clusters are located mostly on the lower trunks of trees and consist of 24-130 glossy, globular or dimpled spheres, each about 1 mm in diameter. Depending on the season, hatching takes place 6-10 days after oviposition.

Caterpillars (Figure 3-14B) of various instars are found anytime between early March and the end of November, with periods of greatest abundance from June to September. All larval instars are hairy and last instars occur in two color phases. One is milky-green, the other, more common one, exhibits a highly camouflaged, brown to greyish-white mottled bark pattern including up to three, more or less distinct dorsal saddles. Caterpillars are solitary feeders and move with great speed and agility when disturbed, including a hopping and ballooning response during the first four instars. Early instars skeletonize *Khaya* leaflets at night and spend the day motionless on or underneath leaflets. Older instars are free feeders and rest on the lower trunk during the day. All instars shun the foliage of just-expanding shoots. There are five instars in males and six in females, each lasting 5-6 days.

Pupae (Figure 3-14C) are found from late February to early December, abundantly so from June to September. They are often hidden under bark scales, or cradled in loose leaf shelters tied together by sparse strands of silk.

The moths (Figure 3-14D) are present from February to mid-November, most abundantly so from May to September. They rest during the day and are attracted to lights at night. The slender male moths are light to dark or reddish brown with substantial plumose antennae, whereas the white to cream-colored females are bigger and more robust with smaller antennae. Males have wingspans of about 40 mm and are able fliers, while their mates with wingspans of about 50 mm are reluctant to take to the air and then are poor fliers. Both sexes have faint to more pronounced grey line markings and a small black dot on each front wing. Before oviposition, the greatly distended abdomen of the female is greenish. Male moths reach adulthood after an average of 41 days of larval development (September/October), females after about 45 days. On the average, each female produces about 200 eggs, laid in several batches. The life cycle of *H. dissimilis* is summarized in Figure 3-15.

While no field control of *Heteronygmia* has been necessary to date, a laboratory study documented full protection of *Khaya* leaves from defoliation by *H. dissimilis*, following topical application of 1% crude, aqueous seed extracts of the neem tree (*Azadirachta indica*) (Rwamputa and Schabel 1989).

Numerous arthropod predators of the caterpillars and pupae observed at Morogoro are believed to be generalists with little impact (Schabel et al. 1988). On the other hand, four hymenopterous parasites (Chalcidae: *Brachymeria feae* Masi; Encyrtidae: *Ooencyrtus* sp.; Eurytomidae: *Eurytoma* sp.; Ichneumonidae: *Theronia* sp.)

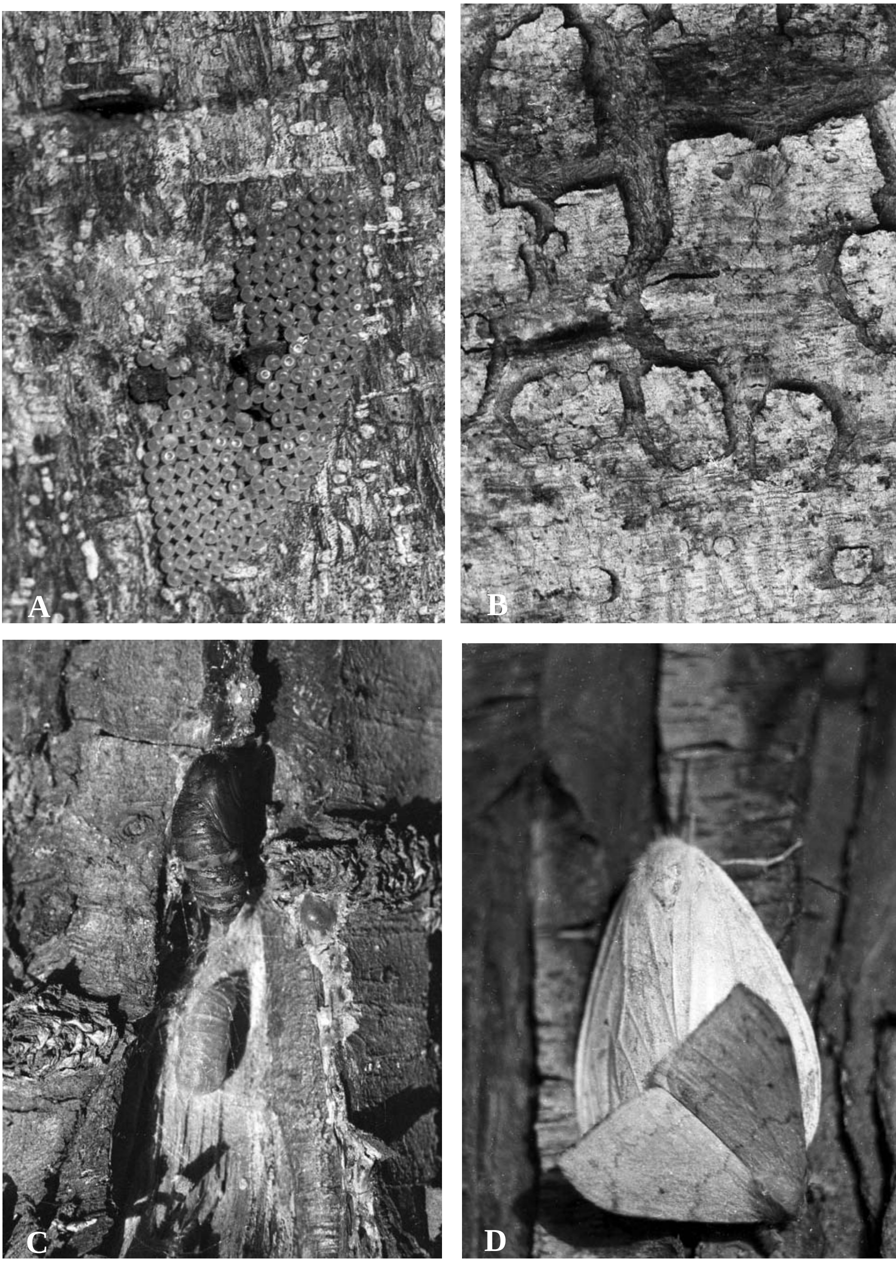


Figure 3-14. Heteronygmia dissimilis (Lymantriidae). (A) Egg cluster (B) last instar larva (C) pupa and (D) mating pair of this defoliator of *Khaya.* Both sexes are represented in Figs. C and D, the larger females being above in each picture.

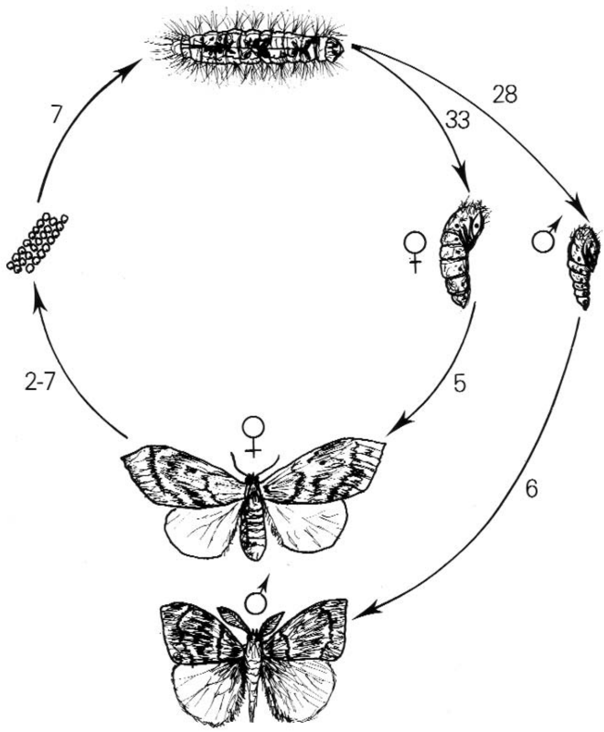


Figure 3-15. Schematic life cycle of the September/October generation of *Heteronygmia dissimilis* (Lymantriidae) at Morogoro. Numbers indicate average days for each stage, 2-7 referring to the oviposition period during the adult life of a female. (A. Schabel).

and two dipterous parasites (Tachinidae: *Exorista* sp. and *Palexorista* sp.) affecting various stages of *H. dissimilis* seem more specific. Seasonally, the egg parasites in particular had significant impacts on this insect and in conjunction with the fungus *Paecilomyces farinosus* (Figure 3-16), which severely decimated pupae and occasionally adults during the rainy season, were responsible for serious setbacks in the annual buildup of *H. dissimilis*. As a result, natural controls seem to be quite effective with this insect.

3.4.2. Orgyia mixta Snell.*: Vapourer Moth*
This tussock moth is widely distributed in Africa with records from Malawi, throughout East Africa, and as far as Guinea (Austarå and Migunda 1971). The more notable among the many hosts include acacias, cypresses, eucalypts, pines, *Jacaranda*, *Schinus molle* and *Ziziphus*. In 1950, caterpillars of this moth were recorded for the first time on exotic softwoods, i.e., *Pinus radiata* in Kenya. Subsequently, several localized outbreaks occurred in other parts of the highlands in that country, but also

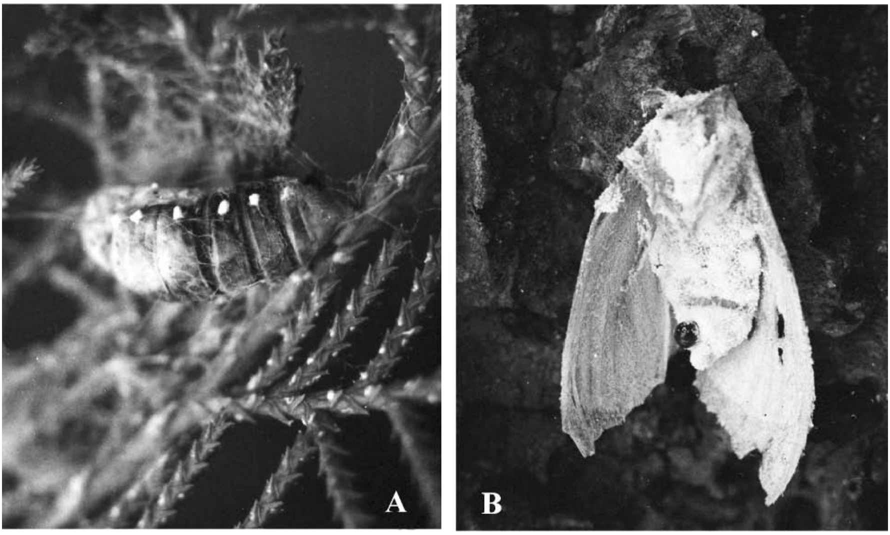


Figure 3-16. (A) Pupa and (B) female of *Heteronygmia dissimilis* (Lymantriidae) killed by the entomopathogenic fungus *Paecilomyces farinosus.* White fungal mycelium is appearing from the spiracles of the pupa, while the moth is covered with sporulating mycelium.

at Amani and in Zambia (Austarå and Jones 1971; Ivory 1977). To this day, *O. mixta* is considered a potentially serious threat to softwoods in Kenya (Nyamai 1996).

The various stages of *O. mixta*, and their biology, are described by Austarå and Migunda (1971). Eggs are spherical white and about 1mm in diameter. Late instar caterpillars reach a length of 22 mm. They have the typical appearance of tussock moth caterpillars. There is a pair of dark-grey pencil tufts on the prothorax and a shorter mid-dorsal one on the 8th abdominal segment. Each of the first four abdominal segments carries a white to creamy-buff dense, short brush tuft, and the second abdominal segment projects an additional pair of dark grey lateral tufts. The cocoons are usually found near the nodes of stem and branches. They are dull brownish-yellow and incorporate some of the caterpillar's body hair in the silk. The adult male moth (Figure 3-17) has a wingspan of 20-25 mm. The grayish-brown of the forewings

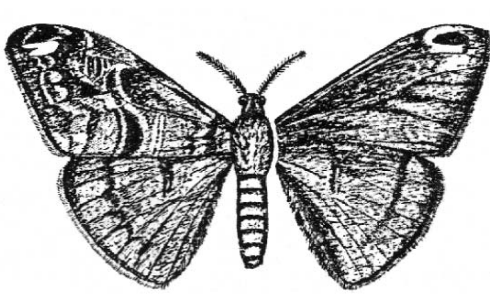


Figure 3-17. Orgyia mixta (Lymantriidae) male, the right half showing underside of wings. (From Reisch 1961; reproduced by permission of Springer Science and Business Media).

has a grey, transverse band half way from the wing base towards the outer margin. Near the outer margin appears an irregular patchy, white band with a prominent spot near the apex. The hind wings are plain grey with a fringe of fine hair. The female is wingless, light brown in color and about 8-10 mm long.

The egg stage lasts from 6-19 days. Young caterpillars disperse by ballooning in air currents. Larvae at first feed gregariously before dispersing. There are four or five larval instars in the male moths, while the majority of females have five or six instars and rarely four or seven. The larval stage lasts 27-60 days. As a result of the caterpillars' wasteful feeding, tree crowns affected appear scorched. The duration of the pupal period is between 6-9 days in females and 13-18 days in males (Ø Austarå, pers. comm.) The emerging female stays with her cocoon and after mating lays an average of 105 (up to 200) eggs inside her empty pupal case. Both sexes live 1-2 weeks. The duration of the life cycle is from 48-85 days and the moth may be able to produce up to six generations a year in Kenya. Due to considerable overlaps between generations, sometimes all stages occur in one place at the same time. About 20-25 larvae per meter branch are considered sufficient to cause 100% defoliation and outbreaks are possible any time of year.

The main agents of natural control are parasitic flies, nematodes and wasps (Gardner 1957a; Migunda 1970). Among the latter are a braconid (*Apanteles africanus* Cam.) and two ichneumonids, *Pimpla mahalensis* Gribodo and *Charops* sp. While *P. mahalensis* is fairly host-vague, the latter is more specific and also more important. This endoparasite of caterpillars has grayish-brown larvae (Figure 3-18A) with an inconspicuous, brown head. At maturity, the larva emerges from the host and spins a cocoon (Figure 3-18B). The adult wasp emerges about two weeks later. This is a black insect (Figure 3-18C) with a brownish tinge on the back of the abdomen, and, in females, an ovipositor. The legs are also brown, except for the dark tarsi. Adult wasps live for up to four days. The efficiency of *Charops* is somewhat diminished by a chalcid hyperparasite (*Brachymeria* sp.).

Based on pesticide trials, Gammalin and Sumithion were recommended at the time, the latter for use near water (Austarå and Migunda 1971).

3.4.3. Miscellaneous Other Lymantriids

While *Bracharoa quadripunctata* Wllgr. was only a minor defoliator of pines at Sao Hill, *Orgyia basalis* Wlk., a close relative of *O. mixta*, proved a more serious defoliator of many herbaceous plants, hardwoods and conifers including pines at Amani, Kawetire, Mbeya, Mufindi and Sao Hill, as well as in Kenya, Uganda and Zimbabwe (Austarå 1968; Austarå and Jones 1971). *Dasychira georgiana* Fawc. attained outbreak conditions in *Pinus patula* at Rongai in 1975, brought to an end by a virus (Mshiu and Kisaka 1983). This species also defoliates young plantations of *Terminalia* in Ghana (Wagner et al. 1991). *Euproctis rubricosta* Fawc. was a defoliator of *Delonix regia*, *Samanea saman* and *Terminalia catappa* in Zanzibar (Le Pelley 1959).

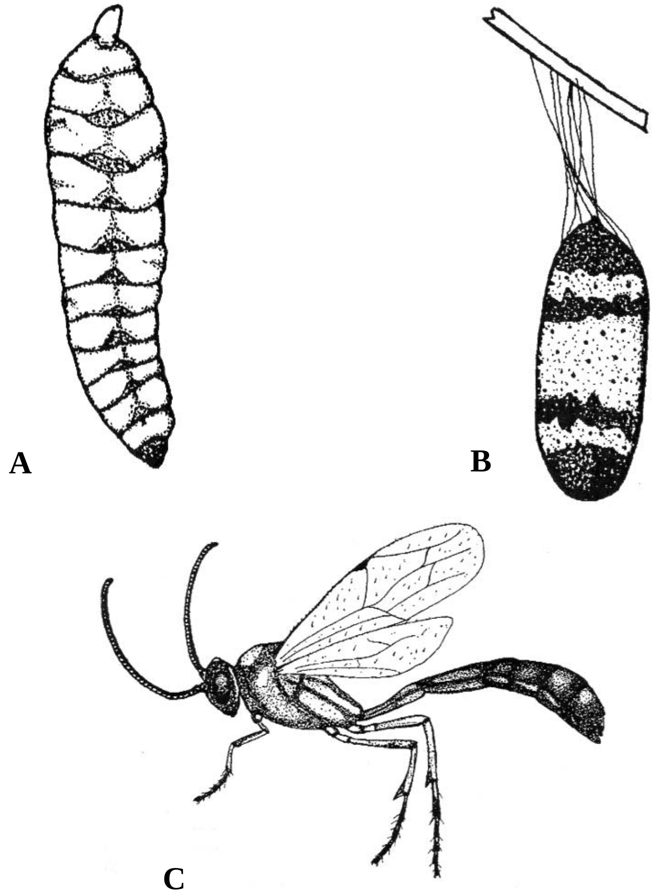


Figure 3-18. Charops sp. (Hym: Ichneumonidae), an endoparasite of *Orgyia mixta* (Lymantriidae). (A) maggot (B) cocoon and (C) adult male. (From Migunda 1970; reproduced by permission of Director, Kenya Agricultural Research Institute (KARI)).

3.5. Notodontidae: Prominents

This family consists of some 3,200 small to medium, mostly brown or gray moths. The solitary larvae tend to carry various protuberances, sometimes resulting in bizarre shapes. When resting, the caterpillars often rear backwards at both ends. Pupae are either naked or contained in cocoons. Prominents feed on a wide range of herbaceous and woody hosts in East Africa (Le Pelley 1959), but to date, only one species gained notice as a pest. *Cerura marshalli* Hamps. caused near complete defoliation of *Populus wislizenii* in a forest nursery at Mbeya, while shunning other species in this genus (Gardner 1957a). As defoliation took place just prior to leaf fall, it was not considered critical and may even have been beneficial by converting the

ageing leaves into fertilizing frass. Adults hatched in August. The larvae have anal prolegs modified into a pair of long filaments or defensive whips, as occurs in some other species of notodontids as well. The species was also reported on the multi-purpose shrub *Dovyalis* in Uganda (Le Pelly 1959).

3.6. Nymphalidae: Brush-footed Butterflies

This family of over 600 species in Africa and at least 220 in Tanzania is the second largest family of butterflies on the continent. Adults have brush-like, greatly reduced front legs. They are attracted to fermenting juices such as ripe fruits and running tree sap, and the males often visit animal dung and carcasses. The caterpillars are often armed with branched spines. A few tree hosts are known for some East African nymphalids (Le Pelley 1959). *Acraea pharsalus* Ward and *Pseudoneptis coenobita* F. feed on *Ficus*, several species of *Charaxes* on *Albizia*, *Bersama*, *Cassia*, *Erythrina*, *Khaya* and *Neptis agatha* Cram on *Albizia* and *Acacia*. As many nymphalids are sought-after by collectors and butterfly houses, host relationships have gained practical significance for butterfly ranching projects.

3.7. Papilionidae: Swallowtails, Swordtails

With two genera (*Graphium* and *Papilio*) and 40 species in Tanzania, this country harbors almost half of the 83 species found in the Afrotropics (Kielland 1990) and most of the species listed for East Africa (Carcasson 1960). Most are forest or woodland dwellers.

These large, elegant butterflies are attracted to flowers, animal urine and their own dead. They, in turn, attract collectors. Despite their name, not all have tail-like extensions on the hind wings. The caterpillars have a characteristic, foul-smelling, extensible fork-like gland (osmeterium) behind the head, which deters predators (Figure 3-19B). Food plants include herbaceous or woody hosts, the latter usually being Annonaceae, Aristolochiaceae, Lauraceae and Rutaceae. While host information may be significant for butterfly ranching, only the following species of swallowtail has occasionally been abundant enough to cause significant defoliation of trees.

3.7.1. Papilio demodocus Esp. (= *P. demoleus* L.): *Orange Dog or Lemon Butterfly*

This is a pest of all species of citrus in the Old World although certain other trees in the family Rutaceae, such as *Teclea nobilis,* are also known to serve as hosts in East Africa (Mansfield-Aders 1919/20; Le Pelley 1959). Caterpillars defoliate the trees, feeding at the edges of leaves of any age and even flowers. While older trees generally tolerate a degree of defoliation, damage to younger trees can be severe, especially since overlapping generations may provide continual attack.

The round eggs are about 1-1.3 mm in diameter. They are pale yellow to pure white and may carry black bands or patches. They are laid singly on the underside of

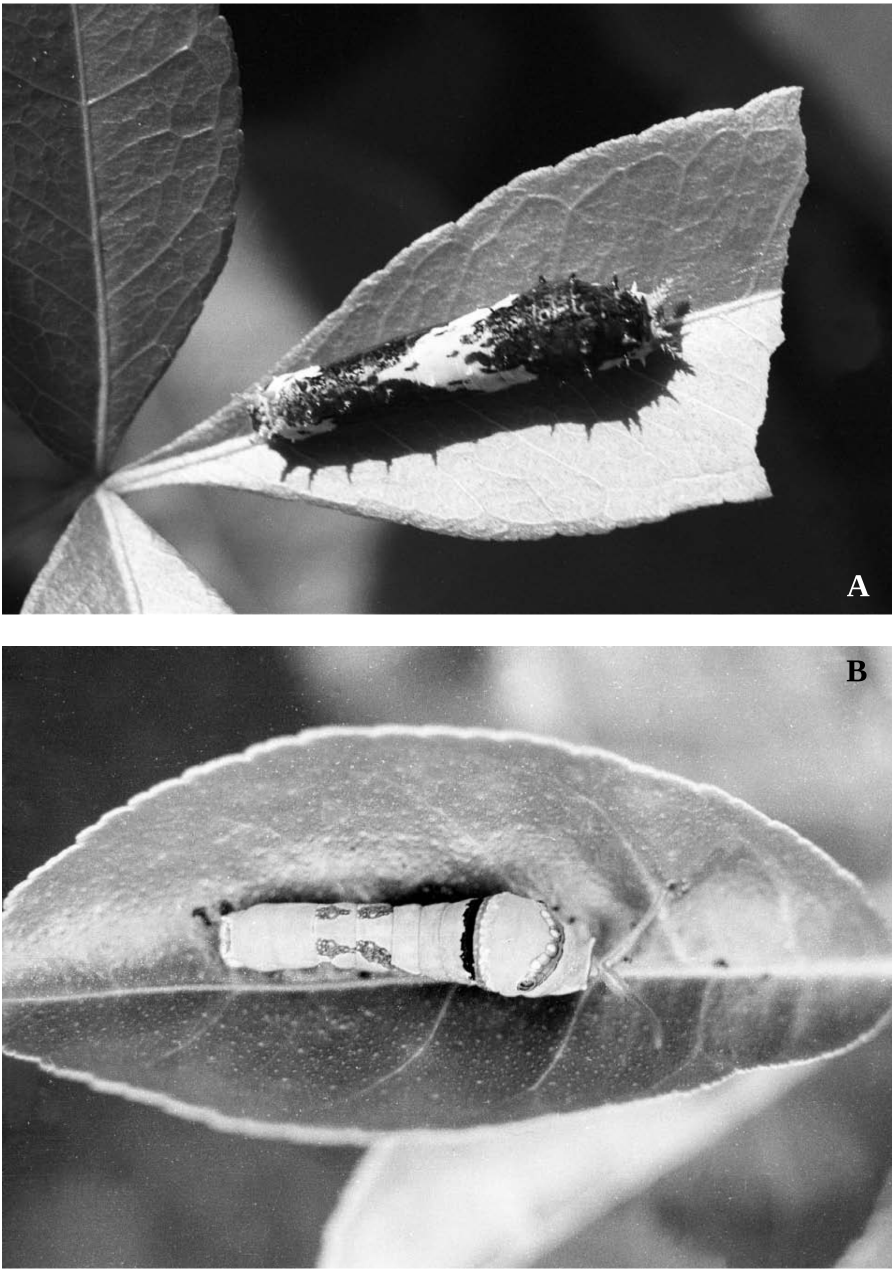


Figure 3-19. (A) Third and (B) fifth instar caterpillars of *Papilio demodocus* (Papilionidae), a defoliator of Rutaceae. Early instars mimic bird droppings. Late instars defend themselves be emitting foul odors from the osmeterium, a fork-like, extendible gland between head and prothorax visible in B.

young leaves near the leaf petiole and hatch after about 4-5 days. The caterpillar stage includes five instars which take a total of about 30 days to develop. Caterpillars of any age sit on the upper side of leaves, usually along the midrib. During the first three instars (Figure 3-19A) their backs are covered with hairy spines and are generally dark brown with yellowish-white markings in the front and back, and a v-shaped white saddle in the middle. This pattern effectively mimics bird droppings. The fourth instar is pale grayish-white and the dorsal spines are much reduced. The fifth instar (Figure 3-19B) can reach 5 cm in length when mature. These older caterpillars are smooth, except for a small pair of projections in the front and another in the back. They are pale green with gray, yellow or black ribbons in various locations. When disturbed, they evert the 1 cm long, y-shaped, yellow, pink or red osmeterium from a fold behind the head, which emits a foul smell. The chrysalis is yellowish-green to brown and about 3-3.5 cm long. It is attached, head up, to small twigs or other objects in the neighborhood of the host plant. Adults hatch after 10-14 days, completing the total development from egg to adult in 38-42 days (Vosseler 1907b). The butterflies (Figure 3-20) are generally dark brown to black with numerous pale yellow patches. Near the inner margin of the hind wings are red and blue eyespots. In Tanzania these active fliers can be seen throughout most of the year. They collect nectar at various flowers, sometimes mass at carcasses of dead animals (Loveridge 1944), and at night may assemble in large groups on shrubs and young trees (Plate 12).

Figure 3-20. Lateral view of *Papilio demodocus* (Papilionidae) with the proboscis extended for sucking liquids. (From Outwater 2000; reproduced by permission of Mkuki na Nyota Publishers, Ltd).

Hand-collecting the caterpillars from small trees is easily accomplished and effective. *Oecophylla* ants prey on the first two instars (Vanderplank 1960).

3.8. Pieridae: Whites, Yellows, Sulfurs

Tanzania hosts 95 species of these small to medium, mostly white and yellow butterflies, including many collectibles (Kielland 1990). These butterflies are often attracted in masses to wet places and have migratory habits. Caterpillars tend to be green and are covered with a short, fluffy pubescence. Relatively few feed on trees, mostly

legumes, but only one is likely to be encountered routinely and in conjunction with visible defoliation. *Catopsilia florella* F., the African migrant has large, whitish green males and yellowish females. The caterpillars defoliate *Cassia* spp. (Le Pelley 1959), also cotton and *Sesbania*. As the common name implies, this is a migratory species, occurring from the Canary Islands across sub-Saharan Africa through Egypt, Israel and Arabia all the way to China, mostly at altitudes below 500 m. Adults fly throughout the year. From November to May, mass migrations have occurred in Dar es Salaam, mostly going North to Northeast, turning East in March and South in May (Outwater 2000). Eggs are laid on both the upper and lower surface of host leaves. The caterpillars (Figure 3-21) reach lengths of up to 45 mm. They are leafy green with cross lines of fine, dark, bristle-bearing tubercles, the head also green and with fine black raised spots. A double line of black and yellow runs along the side.

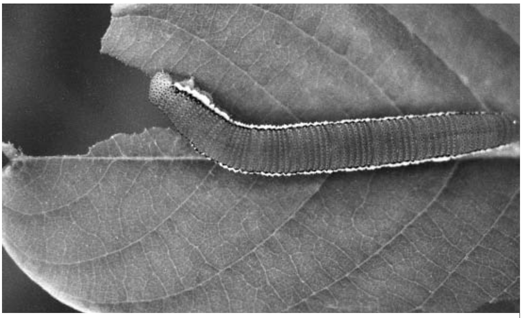


Figure 3-21. Advanced instar of *Catopsilia florella* (Pieridae), defoliating *Cassia.* Mid-January, Morogoro.

3.9. Psychidae: Bagworms, Bag Moths, Case Moths

This is a small family of at most medium-sized moths, whose larvae are defoliators of various plants, including trees. These insects are unique in the way the caterpillars are hidden in a movable silken bag camouflaged by plant materials, and in the extreme case of sexual dimorphism, with the two sexes not showing any similarity. Predation, parasitism, and especially a viral disease (Ossowsky 1960), seem quite effective in the control of bagworms.

The larva, a typical caterpillar, constructs and lives in a protective cocoon-like, silken bag camouflaged with plant parts. When it is on the move to feed, only the head and thoracic legs protrude to the outside. As the insect grows, the size of this bag is gradually enlarged. Just prior to pupation, it is attached to and suspended from vegetation or another object. In order to hatch, the male pupa protrudes from the opening at the lower end of the bag. The males are regular, dull-colored moths, except that their wings are mostly transparent with few scales. They are swift, but short-lived fliers as they do not feed. Their only task is to find a mate. The females are white, fat and grub-like, and have neither legs, nor antennae and eyes. They never leave the bag they develop in, relying on their pheromone to call in a male. Their up to 1,500 eggs (Gardner 1957a) are simply laid inside the pupal shell. The young larvae often find a new host by ballooning off on a silken thread. Some African species are parthenogenetic. In East Africa, only little is known about a few species.

Acanthopsyche reimeri Gaede severely defoliated *Delonix regia* in coastal Kenya (Gardner 1957a).

Kotochalia (=Chaliopsis) junodi (Heyl.), the wattle bagworm, is considered one of the two most important insect problems in plantations of *Acacia mearnsii* in South Africa since 1952 (Ossowski 1957). The species also occurs in Kenya and Uganda but causes little damage there (Curry 1965a).

Semimanatha (=Acanthopsyche) aethiops Hamps. was also listed for Kenya and Uganda (Gardner 1957a; Le Pelley 1959, Austarå and Jones 1971), where it caused locally serious, but short-lived outbreaks on acacias, *E. camaldulensis* and *Pinus radiata* (Gardner 1957a; Curry 1965a; Austarå and Jones 1971).

Eumeta rougeoti Bourg. (Plate 13) occurs widely in East Africa. In Uganda it defoliated cypress, eucalypts, pepper trees and especially acacias (Gardner 1957a). The larval bags are up to 5 cm long cylinders of sticks. Males emerge in December and two months later first instar caterpillars balloon en masse on a communal silk rope. Females lay up to 1,500 eggs.

An unspecified bagworm was reported as having severely skletetonized *Terminalia catappa* in Zanzibar and Pemba (Vosseler 1904-06; Mansfield-Aders 1919/20).

3.10. Pyralidae: Snout Moths

This is a large family of over 10,000 species worldwide, including many pests. They are small to medium moths with narrow triangular front wings and wide, triangular hind wings. At rest, the wings are held roof-like. The caterpillars are frequently associated with webs or tunnels. *Diaphania (=Glyphodes* or *Margaronia) ocellata*, which also occurs in West Africa, often completely skeletonized *Kickxia elastica*, but the trees recovered (Morstatt 1912c). The adults, with wingspreads from 26-32 mm, are white with a shiny, golden edge and spots on the wings.

3.11. Saturniidae: Emperor, Moon, Apollo and Prince Moths

Occurring worldwide, this family of mostly large to very large moths, including the world's largest moth from Asia, is represented with over 100 species in East Africa and at least 72 in Tanzania (Pinhey 1956; Bouyer 1999). Although several African species have been sufficiently serious defoliators of certain hardwoods and conifers to occasionally cause concern from Kenya to South Africa, these insects are generally of greater interest as a source of human food, wild silk and as collectibles, as dealt with in chapter 9.

Emperor moths are densely hairy over most of their body and the broad wings, except for glass and eyespots on the wings, translucent patches often surrounded by colored rings (Plate 14). When confronted by potential predators, the moths spread

their wings to exhibit these owl-like "eyes" as an effective deterrent. Males carry prominent, plumose antennae, females less conspicuous ones. Both sexes are attracted to light, although some species are diurnal fliers. As a result of non-functional mouthparts, the moths live only for a few days. Common emperor moths lay a minimum of 3-4 batches of eggs, each with as many as 20-80 eggs, for a total of up to 300 (Gardner 1957a). A few species are parthenogenetic (Pinhey 1972). The larvae hatch within 2-4 weeks and feed on the empty eggshells before starting to attack foliage, either singly or in groups. The larvae are variable, but many are spectacularly colorful (Plate 15) and adorned with large, sometimes silver or gold tubercles (Pinhey 1972). Food plants listed for a number of the emperor moths found in Tanzania include a wide range of hardwoods from various families, with a slight bias towards legumes (Gardner 1957a, Le Pelley 1959; Pinhey 1956, 1972). Many are polyphagous, which explains the fact that exotic tree species are also attacked. This switch from indigenous to exotic hosts accounts for most of the concern. The caterpillars molt six times within a month before pupating either in a silken cocoon attached to host twigs (e.g. *Argema mimosae* (Bsd.) and *Drepanoptera (=Epiphora) bauhiniae* Guerr.), or underground as most East African species (Gardner 1957a). The pupae diapause for 3-9 months during the dry season, and adults hatch with the rains. Some saturniids appear to have one, others two generations per year (Gardner 1957a; Esbjerg 1976).

Although most East African saturniids are woodland inhabitants, a few species occur in closed forests, including the spectacular frogfoot *Antistathmoptera daltonae* Tams. Unlike some species in Kenya, Malawi and South Africa, only a few emperor moths have to date been minor defoliators of native and exotic hardwoods and a few softwood plantations in Tanzania (Austarå and Jones 1971). The variable prince, *Holocerina smilax* Westw., was observed on *Spathodea* and on pines at Amani and Shinyanga. The variable emperor *Nudaurelia gueinzii* Staud. (Figure 3-22), fed on numerous plants including eucalypts, *Cajanus, Combretum, Croton macrostachys, Cupressus lusitanica, Euclea, Khaya grandifolia, Pinus patula, Prunus* and *Schinus molle* at Amani, Arusha and Meru Uru and also Kenya. The black-eyed emperor, *Ubaena (=Nudaurelia) dolabella* Druce, a day-flying moth, defoliated *Pinus patula* and *P. radiata* at Dabaga, Morogoro, Njombe and in the Rungwe Mts. Caterpillars of the pallid emperor, *Cirina forda* Westw., a species easily recognized by yellow markings and occurring from West to South Africa, fed on young *Casuarina* in Zanzibar, before pupating 75 mm deep in the soil (Mansfield-Aders 1919/20).

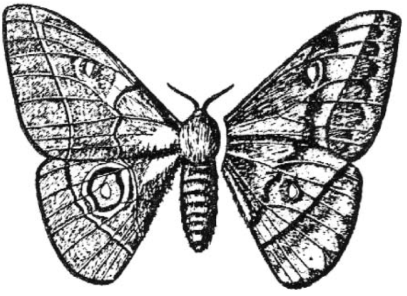


Figure 3-22. Nudaurelia gueinzii (Saturniidae) female, the right half showing underside of wings. (From Reisch 1961; reproduced by permission of Springer Science and Business Media).

In neighboring Kenya *Nudaurelia rhodina* Roths. is known as an occasionally severe defoliator of several conifers (Gardner 1957a, Reisch 1961; Curry 1965c), while in Malawi and South Africa, the pine emperor *Nudaurelia (=Imbrasia) cytherea* is considered a serious threat to pine (Esbjerg 1976). Although occurring in Kenya and Tanzania, the African moon moth, *A. mimosae,* has to date not become a pest in these countries. It is a serious defoliator of *Sclerocarya birrea* in South Africa (Berg 1991).

Hymenopterous and dipterous parasites and diseases often keep emperor moths at economically acceptable levels. During the El Niño rains in January 1998, mortality from a viral disease was evident in a population of *Bunaea alcinoe* Stoll. at Lake Eyasi (Plate 16). A similar incident involving significant mortality of caterpillars of *N. rhodina* had been previously reported from Kenya (Gardner 1957a). In South Africa, pigs were considered for control of the pupae of *N. cytherea* (Gardner 1957a). Many of the moths, the ones that got away, can be observed with typical bird and bat bites taken out of the edges of their large wings.

3.12. Sphingidae: Hornworms, Hawk Moths

There are over 300 species of hawk moths in sub-Saharan Africa (Pinhey 1962). Most are medium to large moths often seen hovering in front of tubular flowers such as jacarandas where they collect nectar with an extendable proboscis that can be up to 25 cm long in certain species. Although some are agricultural pests and a few are tree defoliators, sphingids are on balance mostly beneficial as pollinators. Some hornworms are considered edible and the moths are favorites with collectors, as dealt with in chapter 9.

Their muscular thorax, pointed abdomen and narrow wings give hawk moths the appearance of a streamlined jet fighter plane (Figure 3-23B). The moths are in fact strong fliers and thus many species are widely distributed. For instance, the most common of the 56 species of Sphingidae documented for Morogoro, are almost identical to those in a similar habitat in Sierra Leone (Kingston and Nummelin 1998). Many fly the year round, but in Tanzania they peak late during the rains. Some are diurnal, while most become active at dusk and during the night readily appear at lights. Some stray to heights of 5,000 m on Kilimanjaro (Plate 17). Parasites and bats appear to be major natural controls.

Most hornworm caterpillars (Plate 18) bear a conspicuous horn on the back of the 10th abdominal segment, accounting for their name. Some sport conspicuous eyespots on the thorax, which the larva engage to bluff away potential predators. The caterpillars usually feed solitarily and more or less selectively on a great range of plants, including certain trees. Most are camouflaged, and some are di- or polymorphic, their caterpillars appearing in several colors, depending on host.

Despite the fact that there may be three generations per year (Skaife 1979), sphingids rarely become noticeable pests. During German days, caterpillars (Figure

3-23A) of the oleander hawk moth, *Deilephila (=Daphnis) nerii* L., completely defoliated *Cinchona*, without however causing serious consequences for the trees (Vosseler 1904-06). This species also feeds on mango, *Gardenia* and *Rauvolfia* (Picker et al. 2002). Several other sphingids in East Africa also feed on trees, including: *Platysphinx stigmatica piabilis* (Dist.) on *Craibia* and *Pterocarpus*; *Pseudoclanis postica* Wlk. on *Chlorophora excelsa*, *Trema* and *Celtis*; *Lophostethus demolini* (Angas) on baobab, *Dombeya*, *Grewia*; *Nephele* spp. on *Ficus* and *Diplorhynchus*; *Polyptychus* spp. on *Brachystegia, Cordia*, *Celtis* and *Julbernardia*; *Poliana natalensis* (Butl.) on *Brachystegia* (Gardner 1957a, Le Pelley 1959; Pinhey 1962).

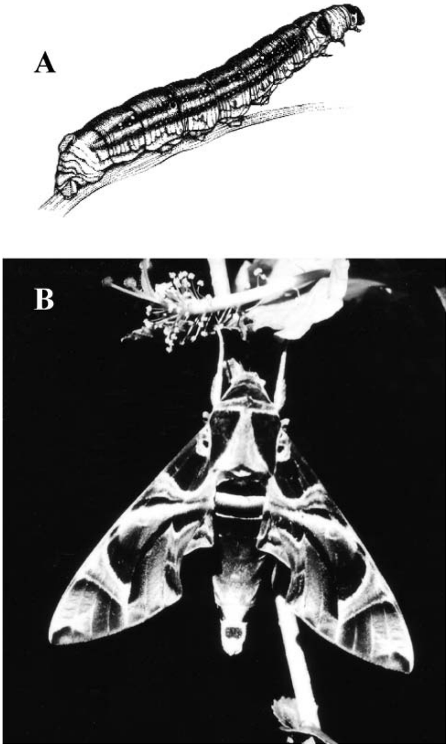


Figure 3-23. Deilephila nerii (Sphingidae), (A) caterpillar and (B) moth. The larvae are defoliators of *Cinchona,* mango, *Gardenia, Rauvolfia* and oleander throughout Africa and beyond in Europe and Asia. The moth was photographed in March in Anambra State, Nigeria. Caterpillars of this species do not carry the terminal horn characteristic of most others in the family. (A. From Pinhey 1974. B. Reproduced by permission of J. Wojtusiak).

3.13. Tortricidae: Budworms, Bell Moths

This is a large family of small to medium moths. When at rest, most resemble the outline of a bell. The slender, smooth larvae live hidden in fruits, buds, near shoot tips and in leaves rolled or tied together with silk. Several species are serious forest pests in the temperate world and others play significant roles in horticulture.

LePelley (1959) listed a *Laspeyresia* sp. from *Albizia* in Tanzania, and several other species in three genera were noted in conjunction with the culture of conifers in Kenya and Uganda (Gardner 1957a; Austarå and Jones 1971). Included were one

species of *Archips*, three of *Epichoristodes (=Epichorista*) and three of *Tortrix*. None was significant enough to warrant further investigation. Best known of the torticid tree pests of East Africa is the false codling moth, *Cryptophlebia (=Argyroploce) leucotreta* (Meyrick). As a pest of fruit, it is mentioned in chapter 7.

4. DEFOLIATING GRASSHOPPERS (SALTATORIA)

The common denominator for this large group are hind legs modified for jumping, in conjunction with front wings that are many-veined and somewhat leathery (tegmina). The hind wings are broad, delicate, with numerous veins and at rest are folded fan-wise under the fore wings. Wings may be absent or reduced, especially in afromontane endemics, many of which are useful as indicators of disturbance and climate shifts (Hochkirch 1995, 1996, 1998; Hemp and Hemp 2003). These are medium to large, bulky insects with chewing mouthparts and a pair of short tails (cerci). Many are equipped with special sound-producing mechanisms and ears (tympana). Most representatives are plant feeders, while some are predators or omnivores. Despite the large number of species, relatively few are forest pests. Among these, some are distinctly arboreal, while others opportunistically feed on trees when other food becomes scarce. Damage results mostly from defoliation, to a lesser extent the destruction of buds or, in some species, from the laying of eggs in tree tissues.

If interpreted as an order in their own right (some taxonomists consider the Saltatoria as belonging to the mega-order Orthoptera, an assemblage including the mantids, cockroaches and walking sticks), the length of antennae is used to separate two suborders of Saltatoria (Gangwere et al. 1997). The shorthorn grasshoppers (Caelifera) include those species whose antennae are shorter than body length and whose ears are at the base of the abdomen. Shorthorns are plant feeders. They make sound by rubbing the hind femora against the tegmina. The longhorn grasshoppers (Ensifera) have long, slender antennae that usually exceed body length. If ears are present, they are located on the tibiae of the front legs. Female ovipositors include conspicuous sword-like appendages. Sound may be produced with special structures on the front wings. Longhorns include plant feeders, predators and omnivores.

4.1. Caelifera: Shorthorn Grasshoppers

Among the families of Caelifera, which include over 500 genera in Africa alone (Dirsh 1965), the following contain species of interest to forestry.

4.1.1. Acrididae

This family of over 10,000 species includes grasshoppers with relatively short antennae. At times, certain species gather in swarms and migrate as so-called “locusts”. Most jump and fly well, while others have reduced wings or none at all. The color of most grasshoppers is cryptic green or brown, but the hind wings may be brightly colored. The tibiae of the hind legs are usually armed with rows of spines used for defense.

No other insects in Africa have been the focus of as much research and for as long as the locusts. On a world map featuring natural factors responsible for “economic uncertainties” (Morstatt 1942), locusts rank along with drought, volcanic explosions, earthquakes, flooding and hurricanes as causes of major disruptions of occasionally biblical proportion. Father Francisco Alvares, one of the first Europeans to explore eastern Africa in the early 1500s, reported traveling five days through country entirely depopulated because of a “very great plague of locusts” where “not a leaf remained upon a tree” and “the earth is left as though it had been set on fire” (Beckingham and Huntingford 1961).

Subsequent travelers frequently made similar observations, such as Volkens (1897b), who spent over a year at Kilimanjaro and described “brown clouds, glistening in the sunlight…millions of locusts” that took hours to pass. Similarly, Kohl-Larsen (1943) experienced several hours of a locust “blizzard” near Lake Eyasi. According to Morstatt (1910c), 1893, 1898, 1903/04 experienced locust epidemics in German East Africa. The outbreak in 1903/04 in Usambara and neighboring areas was extensively documented (Vosseler 1904-1906). During this outbreak, in neighboring Kenya, just north of the border, a layer of locusts buried railroad tracks 10-15 cm deep, reputedly bringing a train to a halt. This, like most other locust outbreaks in East Africa, coincided with November/December.

The intense interest in locusts is primarily explained by their threat to food security since they favor graminaceous hosts. Locusts are, however, extremely polyphagous and during outbreaks no vegetation, including trees, some of them breaking under their weight, are spared. Each locust consumes its own weight (2 grams) in food daily, and one ton of these pests consume as much as 10 elephants or 2,500 people eat per day. Their main habitat is in semiarid savannas and woodland areas, where most of the time they live normal lives as cryptic, “solitarious” grasshoppers. Periodically, however, these insects turn into gregarious locusts, moving as one mob of morphologically and behaviorally different insects. They form nymphal “bands” or adult “swarms” and may remain in migrating mode for years. Large swarms may contain billions of individuals, with about 50 million locusts per km^2 in a medium-density swarm, and up to 80 million in a big one, eating their way across regions and entire countries. Crowding, deteriorating habitat and climatic conditions trigger the transition from solitarious to gregarious phase.

Patanga (=Cyrtacanthacris or *Nomadacris) septemfasciata* (Serv.): The red locust is the most important of the five acridid locust species in Tanzania (Anon 1966). Its permanent home or “outbreak area” is in the Lake Rukwa region of southwestern Tanzania and other wet grasslands in Zambia, Mozambique and Malawi. Despite the fact that this locust has only one generation per year, it becomes a plague with some regularity, chronically affecting Africa from Tanzania southward (Knapp 1973), occasionally with a few extensions northward (Anon 1966). The result is often complete defoliation of most plants, including trees and palm crops (Lever 1979). During the wet season, females lay 3-4 pods with about 100 eggs each. The red, black and

yellow hoppers hatch after about 30 days and during the next 2-3 months undergo 6 or 7 instars in the gregarious or solitarious phase, respectively. Adults (Figure 3-24) are yellow-brown, their hind wings often reddish at the base. Like many tropical grasshoppers they are sedentary while in the solitarious phase and then move only at night. Females are 60-70 mm long, males slightly shorter.

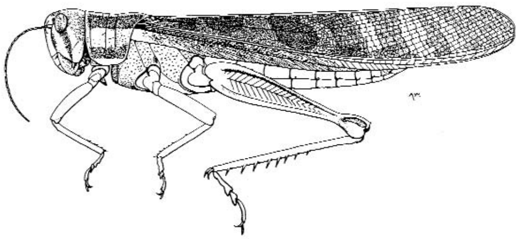


Figure 3-24. Male red locust *Patanga septemfasciata* (Acrididae). (From Dirsh 1965; reproduced by permission of Cambridge University Press).

Schistocerca gregaria Forsk.: While Tanzania can claim main ownership of the red locust, two other locust species, including the desert locust, which generally stays North of the Equator, are sporadic visitors only. From desert-like outbreak centers in the Sahel near the Red Sea and in Pakistan, this locust reaches from West, North and East Africa down to Tanzania, up to southern Europe, and in Asia as far East as India and Bangladesh. Under favorable conditions and with 2-5 generations per year, this locust builds up rapidly. The most spectacular reported flight occurred in October 1988, when large numbers even reached the Caribbean and the northern coasts of South America 6,000 miles from the source. Another major outbreak occurred in 2004 in the Maghreb and from the Cape Verde and Canary Islands, Mauritania/Senegal East to the Chad and Sudan, with swarms still reported on the move eastward in 2005. Nymphs and adults of the two phases differ in color and the adults also in details of the pronotum (Vosseler 1904-1906; Schmutterer 1969). With age, the adults (Figure 3-25) change color from pink, to brown, to yellow when sexually mature. The regional Desert Locust Control Organization for Eastern Africa (DLCOEA), a consortium of seven countries, which has a base in Arusha, Tanzania, conducts surveillance and control operations for this pest.

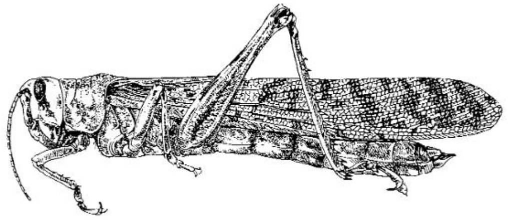


Figure 3-25. Male desert locust, *Schistocerca gregaria* (Acrididae). (From Lepesme 1947).

Locusta migratoria migratorioides R. & F. The African migratory locust (Figure 3-26) also referred to as tropical, plague or hairy-chested locust, tends to be troublesome in West Africa, whenever it enters the gregarious phase from its single outbreak area along the middle Niger River Delta. During outbreak cycles that can last for several years, it reaches from West Africa through East and Central Africa as far as South Africa (Knapp 1973). Solitarious and gregarious individuals differ in color and shape of the pronotum, the former having a crested pronotum, as opposed to a

saddle-shaped one in the latter. In their outbreak area, these locusts have as many as four generations a year, elsewhere, only two are the rule. The last great outbreak was between 1930-40.

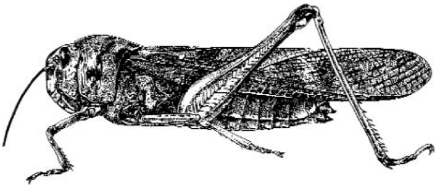


Figure 3-26. Male African migratory locust *Locusta migratoria* (Acrididae). (From Lepesme 1947).

Life History and Management of Locusts. The bionomics of the desert and migratory locust are fairly similar (Vosseler 1904-1906; Anon 1966). At the beginning of the rains (January to March in Tanzania), a total of several hundred oval eggs, embedded in a frothy mass that hardens into a protective egg pod, are laid into the ground in several batches. The female's abdomen is extensible and thus functions as an ovipositor reaching 10 cm deep into the soil (Figure 3-27). Damp soil favors development and high rates of egg survival. The gregarious nymphs hatch after 1.5 –3 weeks. They are at first vermiform and wiggle to the surface before molting into regular hoppers. The nymphal stage lasts about 50 days. The fully winged adults take another 2-3 weeks to reach sexual maturity (Vosseler 1904-1906).

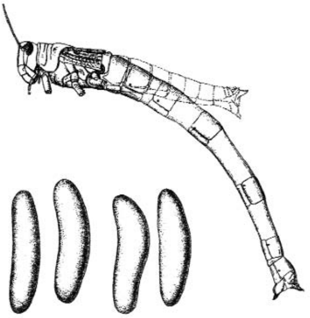


Figure 3-27. Female desert locust *Schistocerca gregaria* with ovipositor fully extended in comparison to normal length. Eggs are 12 days old and start bulging with embryos. (From Vosseler 1904-06).

As no continent is plagued by locusts as much as is Africa, it is not surprising that a "South African Central Locust Bureau" was established already in the early 1900s, followed by International Locust Control Conferences and an International Anti Locust Research Centre headquartered in London. The Biological-Agricultural Institute established at Amani in 1912 was specifically charged to research and manage the "yellow monsters" as one priority. As a result, under the guidance of Vosseler (1904-1906), a fledgling extension program was developed which involved the local population in locust monitoring and control efforts. This program resulted in the training of at least five akidas (Abdallah Sega from Muhesa; Asmani bin Pongwa from Mkuzi; Nyenga bin Mbaruku from Mnyussi; Sengenge bin Muhina from Mwarimba; and Muhamadi bin Salim-Moa from Moa) who reported data on locusts and their experiences with the application of soap emulsions against locusts. These individuals may well have been among Tanzania's first agricultural extension agents.

Control of locusts (Vosseler 1904-1906; Morstatt 1910c, 1942; Anon 1966) has been tried by physical, chemical and biological means including the use of fire, flame-throwers, ditches, toxic baits, pesticide sprays and dusts. Vosseler (1904-1906) concluded that physical methods, such as ditches backed up by walls of corrugated

sheets, as well as burning or the use of home-made soap emulsions (one and a quarter of soap dissolved in 18-20 liters of water, with or without addition of about one liter of petroleum) were most feasible and effective against hoppers. Hazing with smoke and noise remained the only solution against adult locusts. Experiments with the so-called "locust fungus" in the Usambaras apparently yielded mixed results (Vosseler 1904-1906, 1908; Morstatt 1910c), presumably because the fungus was at the time imperfectly understood. Recently, following years of research by the LUBILOSA Consortium, an efficient if costly myco-pesticide with the name "Green Muscle" was developed for grasshopper control in Africa (Babaleye 2001; Lomer et al. 2001). This product is based on the best of 160 strains of the green muscardine fungus (*Metarhizium anisopliae* var. *acridum*) screened, the same fungus tried with less success almost 100 years ago at Amani.

Positive aspects concerning locusts include their edibility by humans and many birds, especially species of bustards, raptors and storks (Vosseler 1904-1906; Anon 1966). Over 1,000 locusts were retrieved from the stomach of one marabou alone (Anon 1966). As Chavanduka (1975) put it, "they ate everything, but they got eaten as well". Outbreaks can also reduce potential flash fuel buildup and thereby mitigate bush fires (Knapp 1973).

Tree locusts. While the previous three species of locusts are not arboreal pests in the strict sense, two other species are. *Anacridium melanorhodon* (Walker) and *A. wernerellum* (Karny) have occasionally experienced localized outbreaks in East Africa and beyond, usually in *Acacia* savannas (Dirsh 1965; Anon 1966; Kamau 1978; Jamal 1994).

The Sahelian tree locust, *A. melanorhodon,* occurs from northern Tanzania into southwestern Arabia and all across the northern Sahel to Mauritania, while *A. wernerellum* reaches from southern Africa through East Africa and across the southern Sahel to Senegal. The ranges of the two overlap to a considerable extent. These locusts can be separated based on a large black band in the hind wing of *A. wernerellum* as opposed to a less developed one in *A. melanorhodon* (Figure 3-28). "Green Muscle" myco-pesticide has been successfully tested against *A. melanorhodon* (Lomer et al. 2001).

4.1.2. Lentulidae

These are mostly small, sluggish, wingless grasshoppers with large head, eyes and thorax. The majority live, often gregariously, on shrubs and trees and tend to be fairly host-specific. Many species are endemic. A few species, *Malawia leei* Dirsh, *Mecostibus nyassae* Uvarov and *Nyassacris uvarovi* Ramme fed on *P. patula* in Malawi, but were not considered economically significant (Esbjerg 1976). Although there are six species of *Mecostibus* in Tanzania (Dirsh 1965), they have not been implicated in tree damage in this country.

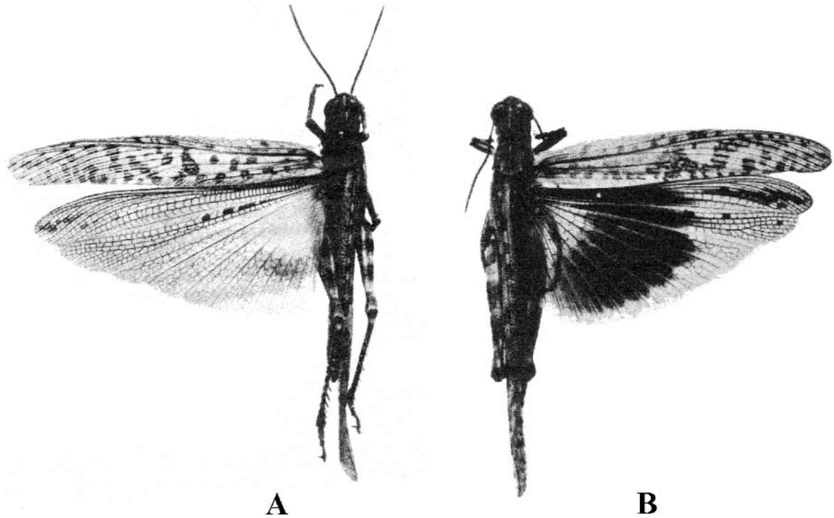


Figure 3-28. Male tree locusts, (A) *Anacridium melanorhodon* and (B) A. *wernerellum* (Acrididae). (From Anon 1966).

4.1.3 Thericleidae.
Only two of 56 genera in this family of about 200 species in sub-Saharan Africa (Gangwere et al. 1997) are known to include tree pests. *Plagiotriptus* spp. Karsch (=*Choroetypus*, *Piezomastax*, *Manowia*) was of special concern, when certain species shifted their food preference from indigenous flora to exotic pines. Previously, *Plagiotriptus* spp. were listed as belonging to the Eumastacidae, a family now considered all-American (Gangwere et al. 1997).

Six or seven species of *Plagiotriptus* are known from East Africa (Lee 1972). The African pine-feeding grasshopper *P. pinivorus* attained prominence after causing persistently severe defoliation of exotic pines, especially *Pinus patula*, in Malawi in the 1960s (Austarå 1965b; Lee 1972; Esbjerg 1976). At that time, significant tree mortality was experienced, mostly on shallow, infertile soils. Smaller scale defoliation of *P. patula* and *P. elliottii* by *P. pinivorus* (probably *P. hippiscus*) occurred at Matogoro forest in 1975/76 (Mshiu and Kisaka 1983) and another of *P. patula* by *P. hippiscus* (Gerst.) at Morogoro in the mid-80s (Schabel et al. 1999). This species is widespread in all three countries of East Africa (Hochkirch 1998). Both of these grasshoppers are highly polyphagous on herbaceous hosts, shrubs and trees. The primary requirement for *P. pinivorus* seems to be access to evergreen or semi-evergreen vegetation in areas of moderate to heavy rainfall, i.e. mostly at altitudes from 1,525-2,135 m, but occasionally as low as 490 m (Lee 1972).

Repeated complete defoliation of *P. patula* by another thericleid hopper, *Chromothericles*, was reported at West Kilimanjaro in 1976/77, and in lower numbers at Mt. Meru (Mshiu and Kisaka 1983).

In Malawi, *P. pinivorus* exhibits three generations every two years, and the complete life cycle takes about one year (Lee 1972). Nymphs and adults have been observed on pines throughout the year, except from December to late January. Mating and oviposition occur throughout this period, but there are two peaks from late October to January and from May to June, resulting in two overlapping generations every 18 months and three generations every two years (Esbjerg 1976). For *P. hippiscus* at Morogoro, mating also peaked from the end of May to the end of June. Both sexes were still observed in August/September and nymphs of about the size of males in mid-February. During copulation the small male assumes a characteristic dorso-lateral position by clinging to one of the hind femurs of the female (Figure 3-29). Both males and females are promiscuous. About 7-20 days after the last mating, females seek bare soil and dig a shallow pit to lay a batch of up to six eggs. They then resume voracious feeding in trees, before laying other batches of eggs at 17-35 day intervals.

Figure 3-29. Male of *Plagiotriptus hippiscus* (Thericleidae) mate-guarding much larger female *on Pinus patula*. June, Morogoro.

Eggs incubate from 49-248 days, with an average of 115 days. The winter population hatches from April to May, maturing in November, while the summer population hatches from December to January and matures from May to July. Within the same batch, an average of 34 days, and a maximum of 88 days may elapse between the first and last hatch.

Nymphal peak emergence and rainfall in February are strongly correlated, allowing prediction of emergence two weeks in advance. Another smaller peak of emergence in August, however, cannot be explained by rainfall. The first instar nymph is ephemeral (about 12 hours), and will molt immediately when reaching the soil surface before feeding on ground vegetation for the next 2-3 weeks. Advanced instars complete their life cycles on trees, each instar lasting about 6-8 weeks. Young instars are wasteful feeders. There are generally six instars for males and seven for females. Despite the extra instar females develop more rapidly and reach adulthood at about the same time as do males.

Adult males (Figure 3-30A) are about 1.5-2 cm long, moderately robust grasshoppers. Their abdomen, shield-like pronotum and greatly enlarged hind femora are strongly compressed. A minute set of non-functional wings, not found on nymphs, is hidden under the pronotum. The thread-like antennae are about one third the length of the head. The abdomen of the male is strongly reflexed over the back. The insect is largely leaf-green, but sports inconspicuous, small areas of blue, pink, red and white on various parts of the legs, wings, antennae and the pronotal ridge. Eyes are golden yellow. Females (Figure 3-30B) are about twice the size of males, more robust and generally less compressed. They are uniformly leaf-green, except for the golden yellow eyes and valves of the ovipositor. Their wings are also minute and hidden under the pronotal shield.

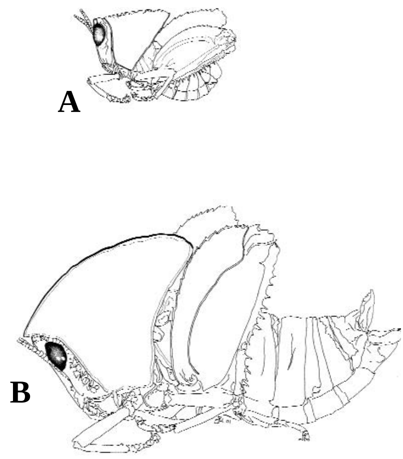


Figure 3-30. (A) Male and (B) female of the African pine-feeding grasshopper, *Plagiotriptus hippiscus* (Thericleidae). (P. Schroud).

Numerous invertebrate and vertebrate predators, including skinks, birds and blue monkeys, as well as a tachinid parasite were documented, but ultimately they were deemed insufficient to reduce populations of the grasshopper to non-damaging levels by themselves. As a result, sticky bands and chemical controls were relied on for monitoring and control purposes, respectively (Austarå 1969b; Lee 1972; Esbjerg 1976). In the 1960s, gamma-BHC at 0.5% proved the most effective insecticide for ground and aerial applications at ultra-low volume formulations in Malawi (Austarå 1969b; MacCuaig and Davies 1972). Spraying of road banks and firebreaks was recomended, as the hoppers clustered there for oviposition in the bare ground. Massawe (1993) mentioned a *Megaselia* sp. being used for biological control of *Plagiotriptus* at Matogoro.

4.1.4. Pyrgomorphidae

Especially the drier parts of Africa harbor 40 genera of so-called bush locusts, or foam and lubber grasshoppers (Dirsh 1965). Many share bright, aposematic colors, large size, gregariousness, sluggish behavior, various stages of wing reduction, and repugnant foams or odors. While the majority is associated with herbaceous plants, some species occasionally defoliate trees.

Phymateus spp. As their common name milkweed locust reflects, these grasshoppers prefer hosts in the dogbane or milkweed families (Apocynaceae, Asclepiadaceae) and they occasionally occur in swarms of many thousands. At the beginning of the dry season, large numbers have been observed flying at altitude and for long

distances (Esbjerg 1976; Picker et al. 2002). These are sturdy, about 7 cm long insects. Eggs are inserted in batches in the soil. Most species are easily recognized by a number of conspicuous excrescences on the pronotum. While generally feeding on non-woody hosts, they occasionally become serious defoliators of *Gmelina arborea* and citrus (Esbjerg 1976; Picker et al. 2002). In March 1983, large numbers of nymphs and adults of the drab, olive-green species pictured (Figure 3-31; Plate 19) completely defoliated frangipani (*Plumeria*) in Morogoro, small exotic ornamental trees in the family Apocynaceae. Five species of *Phymateus* have been reported for Tanzania (Dirsh 1965).

Figure 3-31. (A) Milkweed locusts *Phymateus* sp. (Pyrgomorphidae) severely defoliating frangipani. (B) Close-up of one of these locusts. March, Morogoro.

Zonocerus spp. The so-called elegant grasshoppers or “ngeda” are sporadically severe defoliators of many herbaceous and woody crops. Especially nursery seedlings of coffee, ceara rubber, *Gmelina*, teak, wattle and eucalypts have suffered damage in different parts of their range. Plants attacked are left with ragged-looking leaf remnants. There are only two species in the genus *Zonocerus*, both common and widespread in sub-Saharan Africa (Hill 1983). *Z. elegans* (Thunb.) is reported from East to South Africa, while *Z. variegatus* L. occurs from extreme West Africa into the Congo and Sudan (Merwe and Kent 1925; Dirsh 1965; Bohlen 1973; Hill 1983; Schmutterer 1969). In Tanzania, *Z. elegans* is usually abundant from October to March (Bohlen 1973). Vosseler (1906c, 1907a, 1907d) and Morstatt (1912e) reported *Z. elegans* as a serious annual pest all along the coast and from the East Usambaras to Mombo, especially in January and February. At Kilimanjaro, *Z. elegans* occurs from 800-1,700 m (Hemp and Hemp 2003). It has also been reported from Tabora, Mohoro and Mwanza. In Ghana, *Z. variegatus* recently emerged as a very serious pest of agricultural and agroforestry crops, including teak and *Gliricidia* (Wagner et al. 1991).

In Tanzania, this grasshopper has one generation per year (Vosseler 1906c). The adults live for about 3-4 months. Males typically ride (mate guard) a female for weeks, mating repeatedly during that time (Wickler and Seibt 1985). During the rainy season, mature grasshoppers aggregate at oviposition sites where egg pods can

subsequently be found by the thousands. The sausage-shaped eggs are brown, 6-7 mm long and 1.5-2.3 mm wide. Several pods of 40-100 eggs each are laid about 6 cm deep into the soil, for a total of about 300. The egg pods are embedded in a brownish froth that hardens into protective sponge-like packets. After several months of estivation, nymphs hatch during the rains. They are black with yellow and white lines, patches and dots (Plate 20). Nymphs feed on various weeds for about four months while undergoing five instars. The strikingly colorful adults appear in January. Much of their body is boldly patterned in black, yellow, red and orange against a dark greenish base. Most are short-winged, non-flying individuals (Figure 3-32), while occasionally specimens are fully winged but reluctant fliers. Depending on the degree of wing development, adults are about 3-5.5 cm long. Both nymphs and adults are gregarious.

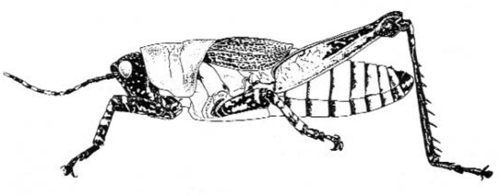


Figure 3-32. Short-winged adult of the elegant grasshopper *Zonocerus elegans* (Pyrgomorphidae). (From Scholtz and Holm 1985; reproduced by permission of the University of Pretoria).

Elegant grasshoppers do little justice to their name other than their colorful appearance. They move sluggishly and eject a clear, repugnant substance from a gland between the second and third tergite. The combination of aposematic color, sluggish movement, gregariousness and repugnant glandular secretions, as is common in this family, is believed to assure protection from predators. Chameleons do in fact shun these grasshoppers (Morstatt 1912e). Other observations do, however, indicate otherwise, as storks, rollers and a small mongoose do not seem to be deterred from preying on these grasshoppers (Vosseler 1907a). Also, in parts of Africa, *Z. variegatus* is considered edible by man (Anon 1994; Malaisse 1997). Since they are polyphagous insects, it is conceivable that repugnancy and toxicity may be a function of particular food plants consumed. Most pyrgomorphids are poisonous and human fatalities from ingestion are known (Picker et al. 2002). Another pyrgomorphid, *Phymateus viridipes* Stål, is also considered edible in the Zambesian region (Malaisse 1997).

Being gregarious, visible and slow, these grasshoppers can be easily handpicked mornings and evenings, starting in December, to be disposed of as garden fertilizer (Vosseler 1906c). Cultivating a few centimeters deep will destroy the subterranean egg masses, but subsequent weeding may force remnant grasshoppers to become arboreal (Morstatt 1912e). In the past, various pesticides were applied, as well as toxic bait based on wheat bran. In 1906, heavy rains caused a fungal disease over a wide area including Amani, Kwamkore and Derema, leading to a crash of the population (Vosseler 1906c, 1907a). Attempts to culture this fungus did, however, fail at the time (Morstatt 1912e). This fungus was most likely *Metarhizium anisopliae*, an industrial formulation of which, called “Green Muscle”, has recently been successfully tested against these grasshoppers (Lomer et al. 2001).

4.2. Ensifera: Longhorn Grasshoppers

Four families of longhorn grasshoppers are of potential interest to forestry in Tanzania, of which two, the *Gryllidae and Gryllotalpidae* are discussed in chapter 8 in conjunction with root-feeding insects. The other two families are interesting in several other contexts.

4.2.1. Gryllacrididae

The leaf-rolling crickets are arboreal, mostly brown insects, that spend the day in shelters of rolled leaves tied with silk. At night they roam to prey on other insects. Unlike crickets with 3-segmented tarsi, these grasshoppers have 4-segmented tarsi.

4.2.2. Tettigoniidae

The katydids or bush crickets are a large family of mostly green or brown species mimicking foliage and bark. A few are colorful (Plate 21). The majority are plant feeders, while others scavenge or prey on other invertebrates. Unless the hopper is host-selective and the host is an abundant crop tree, arboreal species are not likely to cause more than minor damage as a result of either defoliation or oviposition of eggs into the tender bark of twigs,

Katydids are generally large insects, their length ranging from 40-80 mm. Their thin antennae exceed body length, they have 4-segmented tarsi and ears are located on the front tibiae. Some species are wingless or have reduced wings. Males make buzzing or hizzing sounds by rubbing front wings against each other. Females carry a long, sword-like ovipositor. The eggs are laid in soil, plant tissues or bark. Most species are nocturnal and some are attracted to light.

To date only one species of katydid, *Zabalius ophthalmicus* (Walker) (=*Mataeus orientalis* Karsch), was reported as a tree pest in Tanzania, while others are of interest as predators, edibles or collectibles. From September to March, *Z. ophthalmicus* defoliated and destroyed buds of young rubber trees (*Ficus elastica*) in East Usambara plantations. This solitary feeder was also reported from Zanzibar and near Lake Tanganyika (Vosseler 1906c). The bright green front wings mimic lush foliage. Females are 80 mm long, males 60 mm. The jumping legs are weak, their femur purple and red where it joins the tibia. The antennae are typical for the family. A sharp point projects from between the bases of the antennae. The pronotum sports 15-18 shiny small, pearl-like, yellow to black-brown warts.

This insect attacks trees at night and hides on the underside of leaves during the day. Females lay 10-12 narrow, dark grey eggs into slits cut into living branches, which subsequently dry out and often break off. Nymphs are also green, the antennae in early instars eight times the length of the body. They disperse and feed on a variety of native plants. A related afrotropical species, *Z. apicalis*, is also a defoliator of young *Ficus*. It develops from egg to adult in about 100 days (Picker et al. 2002).

Control of *Z. ophthalmicus* relies on collecting the insect in the morning or destroying the eggs. Egg sites can be readily located because the branch swells at the site of oviposition, leaving a scar. Although not abundant, the growing interest in the culture of rubber trees in the early 1900s made this insect a potentially significant pest. A closely related insect had already proved disastrous to the culture of rubber trees in Indonesia.

Ruspolia (=Homocoryphus) spp. The cone-headed or edible katydids are about 60 mm long, uniformly green or brown to purplish, and yellow at the base of the jaws. They are night-active, feeding on grasses and cracking grass seed with their powerful mandibles. Eggs are laid in the ground at the base of grass clumps. Nymphs hatch in 1-2 months and reach maturity in 2-3 months. As a swarming species, these katydids often become damaging in graminaceous crops. Most significant though, they are a popular human food. Although not damaging trees, they abound in woodlands and savannas.

Clonia spp. This katydid is a very large and slender, night-active predator of caterpillars. Because of the powerful jaws this insect needs to be handled with care. Eggs are laid in the ground.

Cymatomera paradoxa Gerst. The bark katydids are 50-60 mm long woodland inhabitants. Unlike many katydids that are green and hold their wings roof-like, these katydids are mottled grey-brown and their forewings are held flat (Figure 3-33A). As a result, a resting specimen blends well with bark and lichen. If these night-active insects are disturbed during the day, they raise both pairs of wings in a warning display (Figure 3-33B), revealing the colorful abdomen.

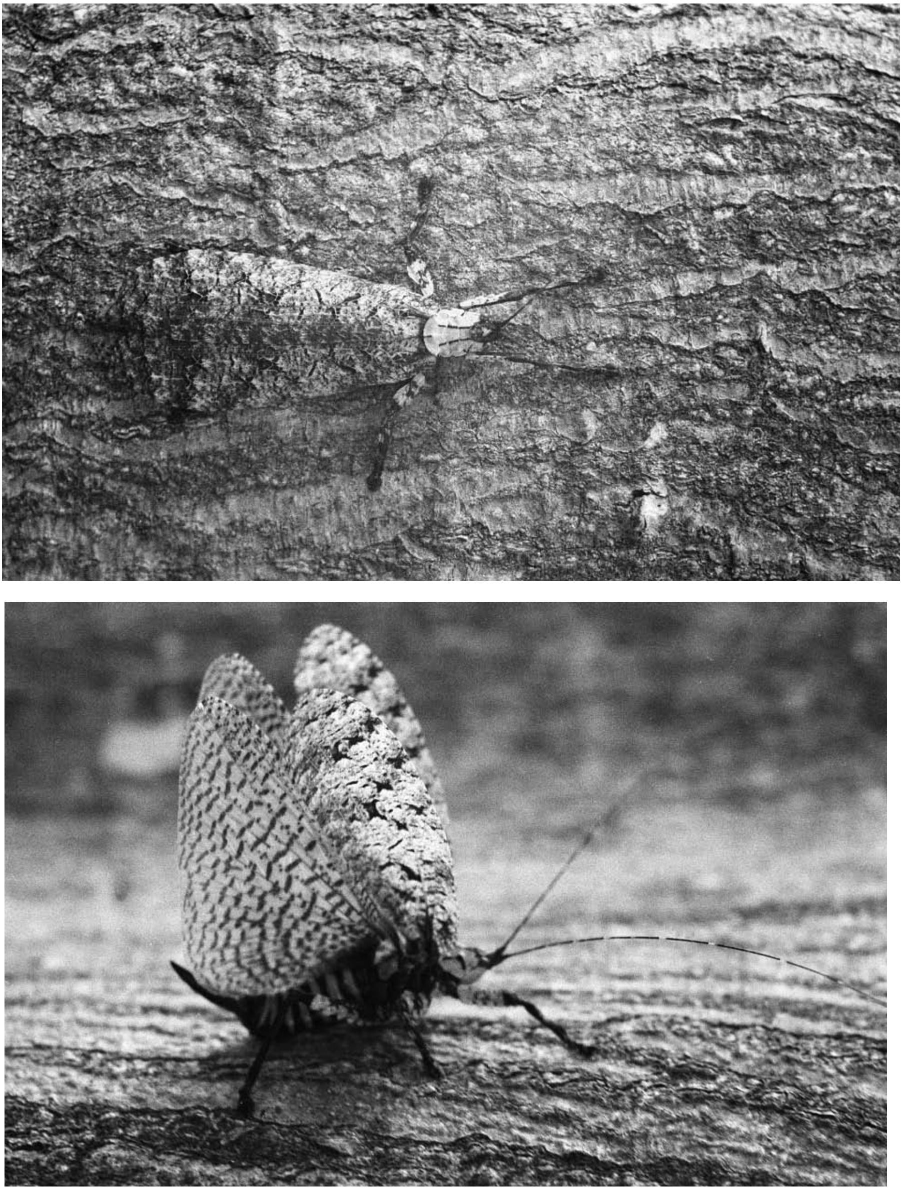


Figure 3-33. Cymatomera sp. (Salt: Tettigoniidae), one of the bark katydids, (A) while resting on bark and (B) in threat posture. Mikumi.

CHAPTER 4

SAP-FEEDING INSECTS

1. INTRODUCTION

Depending on taxonomic point-of-view, there are either two (Thysanoptera and Hemiptera) or three (Thysanoptera, Homoptera and Heteroptera) insect orders containing sap feeders of plants. Since the Thysanoptera from Tanzania are mostly agricultural pests, and the few known to attack trees mostly affect fruit trees, this order will be only briefly introduced before giving closer attention to the more important Homoptera and Heteroptera, jointly referred to as Hemiptera. All sap suckers thrive on healthy hosts.

2. THRIPS (THYSANOPTERA)

The order thrips consists of over 4,500 species of insects less than 3 mm long. Included are many plant-feeding pests, but also predators of mites and various small insects including other thrips (Palmer et al. 1989). While many are dry season pests of agricultural crops, relatively few are serious tree pests, and those affect mostly ornamental and fruit trees.

Aside from their small size, thrips are characterized by having a very narrow cylindrical or spindle-shaped body, asymmetrical mouthparts arranged in a cone, eversible, bladder-like tarsi and two sets of slender wings fringed with long hairs. Development occurs in three stages plus a resting stage that resembles a pupa, which can move if coerced. Many thrips are parthenogenetic. Their eggs are laid into plant tissues.

Thrips extract sap and cause lesions or deformities of the tender parts of plants. They also vector plant pathogens. Little is known about Tanzanian forest thrips and only slightly more about those attacking fruit trees (Hill 1983). Among those mentioned by Jacot-Guillarmod (1970) and Strassen (1960) as occurring on forest trees in Tanzania are: *Dendrothrips jeanneli* Bagn. on *Kigelia pinnata*; the predaceous *Franklinothrips* spp. on various trees including *Trichilia emetica*; *Mymarothrips ritchianus* Bagn. on *Syzygium* and *Maesa*; and *Rhipiphorothrips jacoti* Pries. on *Combretum*. Only the black tea thrips, *Heliothrips haemorrhoidalis* Bouche was

reported as being abundant on a conifer, i.e., *Pinus radiata* in Kenya, causing grayish foliage with, however, no serious effects (Gardner 1957a). This may be the same black thrips that Morstatt (1912c) had reported as causing leaf spots and leaf mortality on ornamental *Dracaena*. Another unnamed thrips caused some damage to the foliage of ceara rubber trees (Vosseler 1904-06).

3. BUGS (HEMIPTERA)

3.1. Introduction

This huge assemblage of over 100,000 species of very small to large insects in as many as 134 families incorporates those insects with typical piercing-sucking, cicada-style mouthparts, i.e., a hollow, quiver-like beak containing three arrow-like stylets used for drawing sap from plants or animals. The front wings are larger than the hind wings, although wingless forms are common, and, rarely, two-winged forms also occur. Aside from the mouthparts, the Hemiptera are variable and taxonomists still disagree on a classificational system. Primarily based on differences in the front wings and the position of the beak (rostrum, proboscis), this order is frequently split into two separate orders, the Homoptera and Heteroptera. A lumped approach is taken here, and the most important groups of tree-damaging representatives are discussed in three suborders. The first two, Auchenorrhyncha and Sternorrhyncha, are often combined as one order, the Homoptera.

3.1.1. Damage

The Hemiptera attack any succulent tree part and, in the process, may cause serious damage of several kinds (Weber 1930; Schaefer and Panizzi 2000). By piercing plant tissues, they cause injury and frequently vector viruses and phytoplasma diseases. By extracting sap, they deplete hosts of resources and weaken them. Furthermore, the saliva of certain species of Hemiptera is toxic, which results in hormonal and physiological imbalances in the host. A few injure living bark when inserting their eggs with a sharp ovipositor. Still others release a sugar-rich liquid called honeydew, which serves as a medium for sooty mold fungi that can form crusts on foliage and block photosynthesis. Honeydew also accounts for frequent associations of these insects with ants as discussed in chapter 6. Symptoms of hemipterous attack include galls in new growth, discoloration, foliar crinkling, crumpling and other distortions, lesions, shot holes, tatters, cankers, dimpling, scabbing, gummosis, multiple leaders, brooms, wilts, stem dieback, retarded growth, premature leaf drop and death.

3.1.2. Management

As stomach poisons applied to plants externally are not effective, the control of Hemiptera usually requires the use of systemic pesticides. In German colonial days, the use of a “cheap, simple, effective, proven and versatile” homemade petroleum-soap-water emulsion was, however, advocated as an excellent contact pesticide for

control of the small sap feeders (Vosseler 1905e). Natural controls and biological methods are often effective, especially against exotic aphids (Le Pelley 1959). A number of Hemiptera are themselves predators of various arthropods, including other Hemiptera, and have been deployed for the biological control of pests.

3.2. Suborder Auchenorrhyncha

This group of about 50,000 small to large species (McKamey 1999) includes the hoppers, spittle bugs, lantern bugs and cicadas. These are active insects, many being agile jumpers. All are strictly plant feeders, and some are fairly host-specific or alternate hosts. They tap the nitrogen-poor vascular system of hosts intra-cellularly. Their front wings are membranous throughout and the beak arises from the chin part of the head, i.e., on the underside next to the thorax. They have three-segmented tarsi and inconspicuous, bristle-like antennae. There are five instars. Cicadas are discussed in chapter 8, as there is greater concern for their impact as root feeders under ground than as sap suckers above.

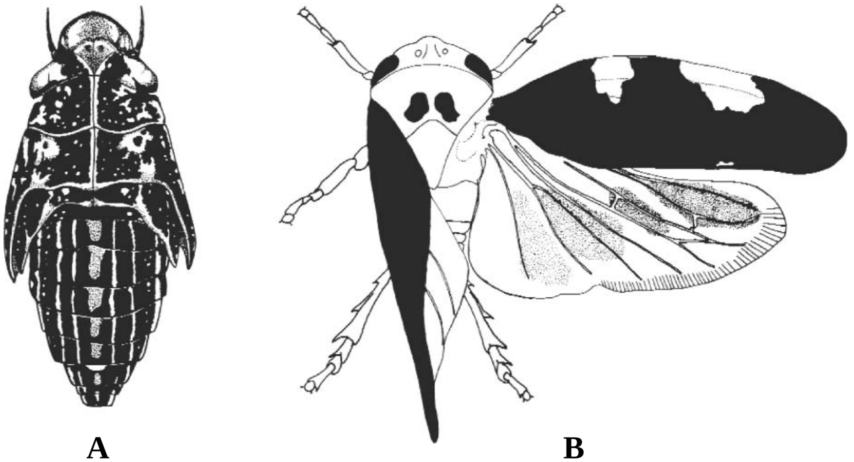
3.2.1. Cercopidae: Spittle Bugs, Rain-tree Bugs; Froghoppers

Froghoppers are common in Africa (Villiers 1952). The nymphs are called spittle bugs, as they secrete and are concealed in spittle-like foam that protects against enemies and desiccation (Plate 22). This foam results from a mix of anal secretions, glandular slime and air. Nymphs have an almost closed concavity on the underside of the abdomen, which serves as a chamber for mixing of the spittle ingredients. Both stages of cercopids are sap feeders and thus affect tree growth to some extent. In the temperate zone a few species with toxic saliva are serious forest pests.

Ptyelus spp.: *Rain-tree Bugs.* While none of the East African species of spittle bugs has been implicated in more than minor damage and their biology is largely unknown, this genus usually attracts attention because of the phenomenon of “raining” trees. During periods of flush plant growth, trees heavily infested with the nymphs profusely shed droplets of liquefied spittle, as observed by Vosseler (1905d) in natural forests and plantations at Amani. Sharp sounds such as hand clapping supposedly provoke brief showers of this “rain”, heavy enough to puddle underneath the trees. Le Pelley (1959) listed *P. grossus* F. and *P. flavescens* F. for East Africa, the former occurring from South into equatorial Africa (Picker et al. 2002), the latter throughout the Afrotropics (Villiers 1952). Host trees include many legumes (*Acacia, Albizia, Erythrina, Lonchocarpus, Tipuana, Peltophorum, Samanea*), but also *Ceiba, Chlorophora, Eucalyptus, Ficus, Grevillea, Morus, Rauvolfia, Rhus* and *Strychnos* (Vosseler 1905d, Le Pelley 1959; Picker et al. 2002). In West Africa, *P. grossus* is considered a potentially serious pest of *Sesbania* (Wagner et al. 1991).

The unidentified rain-tree bug nymphs observed by Vosseler (1905d) at Amani were considered two species but may have been different instars of one species. The first was yellowish-green with two black-blue lines on the head and abdomen. The

underside of the head and thorax, as well as the legs, eyes and parts of the wing buds were black. The second had red eyes, was pale yellow with grey-black speckles and had four light longitudinal stripes along the back. The underside of the head was black, that of the thorax and abdomen, as well as the legs, yellow-white. Nymphs (Figure 4-1A) of these bugs move sluggishly and do not voluntarily abandon their protective foam before molting into adults. There are typically several nymphs per spittle mass. Based on the duration of the “rain”, the nymphal period of these insects is assumed to last about 3-4 weeks (Vosseler 1905d). The winged adults (Figure 4-1B) disperse to various lush plants on which they feed by sucking sap. While most froghoppers are only 6-8 mm long and drab colored, adults of *Ptyelus* spp. are over 15 mm long, have wingspans of 30-45 mm and are colorful. Adult froghoppers jump and fly. Unlike some related hoppers, they do not produce wax. They can be readily identified by a circle of sturdy spines at the distal end of the hind tibiae.



A **B**

Figure 4-1. The rain-tree bug, *Ptyelus* sp. (Cercopidae). (A) Late instar nymph and (B) adult. (B. Anderson and P. Schroud, respectively).

3.2.2. Cicadellidae (=Jassidae): Leafhoppers

This is a large family with numerous African species. Although economically important in horticulture and agriculture, and to a minor extent in temperate zone forestry, the role of these bugs in African forestry is little known. Le Pelley (1959) listed only four relevant species from East Africa, including *Erythroneura* sp., *Jassus subolivaceus* and *Selenocephalus* sp. on *Acacia mollissima*, as well as *Penthimia* sp. on *Ficus*. A search on other trees would undoubtedly yield many more species. Foliage damaged by these sap-feeding hoppers appears mottled or stippled, and, in serious cases, entire leaves dry up with “hopper burn” and drop prematurely. A more serious concern is the fact that this family includes numerous documented cases of vectoring viruses

and other plant diseases. The classification of leafhoppers is still in flux, with some taxonomists arguing for as many as 16 separate families (Skaife 1979).

Leafhoppers are small, usually less than 20 mm long, delicately slender insects, widest in the front and narrowing towards the abdominal tip. They are either colorful or cryptic, and share elongated hind tibiae carrying one or more longitudinal rows of spines. They sometimes occur in groups, usually on or under foliage. When disturbed, they readily escape by jumping and flying. Many leafhoppers are more or less host-specific on certain grasses, herbs or woody plants, while others are polyphagous.

Jacobiasca (=Empoasca) lybica (De Berg.): *Cotton Jassid.* Since nothing is known about the biology of most East African tree leafhoppers, this species, which occurs from Spain and North Africa to Israel, Saudi Arabia and down into East Africa, may serve as a typical representative (Schmutterer 1969). This hopper attacks many crops, most seriously cotton, but of its wild hosts, the tree *Balanites aegyptiaca* is among the most important. The banana-shaped eggs, about 0.7-0.9 mm long, are inserted in veins on the underside of succulent leaves and petioles. Nymphs hatch after 6-10 days. There are five instars. Nymphs are mobile, characteristically moving sideways. They hide under leaves during the day and move onto the upper surface in the evening. The nymphal stage lasts 8-16 days and total development from egg to adult takes about 2-4 weeks. There can be several generations per year. Populations build up, sometimes explosively, after rains and decline with progressing drought. The adults migrate with the wind. Ladybeetles, lacewings, anthocorid predators and some hymenopterous parasites seem unable to stem serious buildups.

3.2.3. Membracidae: Treehoppers

This family of over 3,200 species worldwide, includes many representatives common in Africa. They are mostly less than 6 mm long. Unlike other insects, the first thoracic segment of adults is fashioned into a shield that can reach to the tip of the abdomen and is often adorned with bulbous or thorn-like extensions. As the insects rest on twigs of trees, their mostly brownish or greenish color and these extensions afford them superb camouflage. Nymphs are also somewhat unusual, because their abdominal tip is elongated into a whip, presumably serving for defense. Both nymphs and adults are sap feeders mostly on trees and shrubs, but are considered only minor pests.

Many treehoppers favor leguminous trees. *Centrotus laxatus* Dist. was reported on *Erythrina abyssinica*, while *Oxyrhachis pandatus* Dist. and *Spalirisis alticornis* Jac. occur on *Acacia mollissima* (Le Pelley 1959).

Not much is known about the biology of African treehoppers. Eggs are inserted into cuts made in bark. The nymphs are sometimes gregarious and are often tended by ants that relish the honeydew they produce. In some species, ants build protective shelters (“cowsheds”) for the nymphs. The hoppers live for a few months.

3.2.4. Flatidae: Moth Bugs; Flatid Planthoppers

These bugs have broad and large, fan-like, triangular hind wings folded steeply over the back and often dusted with wax. As their common name implies, they appear moth-like. Some flatids (e.g. *Ityraes gregorii*) have a tendency to rest gregariously on milkweed vines, each adult equidistant from its neighbor and facing in the same direction, giving this assembly the uncanny appearance of a beautiful leguminous inflorescence (Plate 23). When approached, this “flower” explodes into flying “petals”. The nymphs are entirely covered with wax and trail curled terminal wax filaments. Most flatids are of greater interest as objects of natural history than as pests.

3.2.5. Fulgoridae: Lantern Bugs, Snout Bugs; Planthoppers

Some of the larger members of this family are spectacularly colorful and have the front of the head elongated into a hollow, horn-like projection often with extensions (Skaife 1979). In others, like the 31 mm long twig snout bug, *Zanna (=Pyrops)* spp., this extension resembles a broken branch, a camouflage sham enhanced by their pinkish-brown color, peppered with black. All planthoppers can be distinguished from related families by the combination of a swollen first antennal segment bearing a small bristle and a network of veins in the fan-like basal (anal) area of the hind wings (Picker et al. 2002). Some secrete long threads of white wax trailing the abdomen during flight. The gregarious nymphs are often covered with similarly long, curled, waxy filaments, making them conspicuous.

A few of the lantern bugs are minor pests of trees in Tanzania, including *Metaphaena cruentata* Gerst. on *Grevillea robusta* and *Ficus*, and *M. militaris* Gerst. on *Entandrophragma* (Le Pelley 1959).

Lantern and moth bugs share with other members of the superfamily Fulgoroidea two simple eyes and antennae that arise on the sides of the head beneath the eyes.

3.3. Suborder Sternorrhyncha

This is a diverse group of about 16,000 sap feeders, including aphids, scale insects, whiteflies and jumping plantlice. They share with the previous suborder strict plant-feeding habits, the potential to vector pathogens, the fact that front wings are membranous throughout, and mouthparts that arise from the chin part of the head near the thorax. Most are intracellular phloem feeders, consuming a diet rich in carbohydrates but poor in nitrogen. Their honeydew attracts sooty mold fungi, ants and other sugar-loving insects. They differ from the Auchenorrhyncha by having one- to two-segmented tarsi, long, thread-like antennae and by being smaller, relatively inactive, sedentary insects. Many species include atypical forms.

Given the large number of species, the Sternorrhyncha are usually divided into four superfamilies, three of which include species of importance to forestry.

3.3.1. Superfamily Aphidoidea: Aphids, Plantlice

Aphids, of which there are about 4,400 species, are mostly inhabitants of the temperate zones. They are small, 1-8 mm long, soft-bodied insects with winged and wingless adult generations. Most are gregarious and about 90% occur on one host, while the remainder also require alternate hosts. Many are host-specific. The life cycle of aphids tends to be complex, including winter hosts, summer hosts, winged and wingless forms, sexually and asexually (parthenogenetically) reproducing forms, egg laying (oviparous) generations and others giving live birth (ovoviviparous) (Eastop 1958). During favorable times of the year, the wingless, parthenogenetic, ovoviviparous form tends to be dominant, while the winged, mating and oviparous form prevails when food quality or weather deteriorate or hosts become crowded (Esbjerg 1976). In East Africa, the sexual forms (sexuales) are scarce, and there is no migration from primary to secondary hosts (Eastop 1958). The egg stage coincides with the dry season. Four instars are the norm and many species are gregarious.

As ant-tended aphid populations tend to build up, so do honeydew and sooty mold deposits on foliage. Predators like larval and adult ladybeetles (Coccinellidae) and lacewings (Chrysopidae), as well as hoverfly larvae (Syrphidae) and parasitic wasps often suppress population upswings (Murphy et al. 1991).

Of the three aphid families, two are of interest to East African forestry. While overall they are minor forest tree pests, several species posed a major challenge to plantation forestry in East Africa during recent decades after being disseminated through the international plant trade.

Aphididae: Aphidids, Greenflies. Although, strictly speaking, the common name "aphid" applies only to the superfamily, and the term "aphidid" more appropriately refers to this family, the name "aphid" will continue to refer to both. Worldwide this is a large family, but there are relatively few indigenous aphids in East Africa. Of some 80 species reported there, only one third are peculiar to the continent, and only slightly more than a dozen species are associated with mostly exotic tree species (Eastop 1958; Le Pelley 1959).

Greenflies are between 1.5-5 mm long, mostly green, yellow, brown or black. Their body is pear-shaped and characteristically bears two tube-like dorsal "stickers" or bumps (cornicles or siphunculi) near the tip of the abdomen. Winged forms have two pairs of membranous wings, which, at rest, are held roof-like. The front pair is larger and extends beyond the abdomen. There are few veins. The thread-like antennae, about two thirds of the body length, have 3-6 segments. The long and slender hind legs carry two-segmented tarsi.

The most important tree aphids in East Africa are two recently introduced exotic species affecting exotic plantation conifers.

Cinara (=Cupressobium) cupressivora Watson & Vögtlin *(=Ci. cupressi* (Buckton)): *Giant Cypress Aphids.* The taxonomy of cypress aphids is confusing. The former

species name *Ci. cupressi* (Buckton) now applies to a species complex "*Cinara cupressi*", of which *Ci. cupressivora*, the species causing damage in Africa, is only one representative (Watson et al. 1999). The species complex originates in the palearctic region where it is widely distributed on species of Cupressaceae, including *Chamaecyparis*, *Cupressus*, *Juniperus*, and *Thuja* (Ciesla 1991c). The species *Ci. cupressivora* is believed to have originated on *Cupressus sempervirens* somewhere between eastern Greece and the Caspian Sea (Watson et al. 1999). *Ci. sabinae* (Gillette & Palmer) and *Ci. cupressi* (Buckton), two of the remaining species in the complex, probably originated in North America.

Cinara spp. are associated with twigs and branches of conifers. Although they are rarely serious in their native range, *Ci. cupressivora* in a short time earned the dubious distinction of being the most serious and consequential of the exotic conifer aphids accidentally introduced into East Africa to date. It severely impacted populations of exotic cypress (especially *C. benthamii, lindleyi, macrocarpa* and *sempervirens horizontalis)*, as well as other exotic conifers such as species of *Callitris* and *Widdringtonia*. Unfortunately, the most popular of the plantation cypresses, *Cupressus lusitanica*, proved the most sensitive. On the other hand, native *Juniperus procera* is not highly susceptible, and *C. arizonica*, *funebris* and *torulosa*, as well as *Cupressocyparis leylandi* and *Thuja* ssp. proved tolerant or resistant (Obiri 1994). Damage, which is most prominent during the dry season, results from the communal feeding of nymphal and adult aphids on smaller branches of the host, especially where densities of 100 or more aphids per 10 cm sections congregate. Their supposedly toxic saliva (Mills 1990) leads to a yellowing and browning of foliage and eventually progressive branch dieback that typically spreads from the inner crown outward and from the lower crown upward (Plate 24). Heavily infested trees frequently die. In Kenya and Tanzania, seed production in seed orchards of *C. lusitanica* dropped substantially as a result of the cypress aphid (Obiri et al. 1994; Orondo and Day 1994). Honeydew and sooty mold are secondary problems.

The cypress aphid was first discovered in 1986 in Malawi, arrived in Mbeya Region of Tanzania in 1987, then rapidly swept through parts of Burundi (1988), Rwanda and Uganda (1989) and in 1990 reached Kenya, Zimbabwe and Zaire. In all these countries cypresses and relatives played significant roles as plantation species, ornamentals and as key agroforestry components in windbreaks and in live hedges. (Ciesla 1991a,b). By 1991, the aphid had killed 27.5 million cypresses and caused growth loss in another 9.1 million annually in East and southern Africa (Odera 1990; Murphy 1996). The trees killed in these eight countries were valued at US $ 41 million (Odera 1990). A close relative of the cypress aphid, *Cinara tujafilina* (del Guerico), has also been recorded from cypress in southern and eastern Africa, but is considered a minor pest (Anon 2000).

Ci. cupressivora is 1.8-3.9 mm long (Blackman and Eastop 1994). Adults occur in both winged and wingless forms, the former being restricted to the cooler seasons. Both forms are tan and brown. Their dorsum is dusted with pale grey wax making a

pattern of cross-bands. For a homopterous insect, the rostrum of cypress aphids is remarkably short. As is true for many aphids, the life cycle of this aphid is complex (Ciesla 1991a,b,c). Females give live birth to nymphs. The rapid population increase of the cypress aphid in East Africa is partly attributed to the fact that efficient natural enemies were absent, and that, especially in warm climates, parthenogenetic reproduction occurred throughout the year. As in other *Cinara* spp., there is no host alternation.

Chemical, cultural, genetic and biological solutions were tried to deal with the intruder. Pesticides often came too late to save severely damaged plantations or trees. Also, the woolly cover on the aphids was found to impede the efficacy of contact pesticides. For cost reasons and the need for careful timing, pesticides were only considered feasible for the protection of high value trees (Ciesla 1991c).

Thinning was suggested to reduce shade and thus create less favorable conditions for the aphids.

As certain species of Cupressaceae are tolerant of the aphid, and individual trees even in the more susceptible species are often unaffected, genetic control promises some options (Ciesla 1991c; Owuor 1991; Orondo and Day 1994; Memmot et al. 1995; Kamunya et al. 1997, 1999). For the time being, whenever planting cypresses, *Cupressocyparis leylandii* appears to be the best alternative to *C. lusitanica* (Obiri 1994; Obiri et al. 1994).

Based on the fact that many parasitoids of aphids have narrow host ranges, and spectacular successes had been obtained with biological control of various Hemiptera elsewhere, this was considered the most promising approach in the battle against the cypress aphid (Mills 1990). Biological control had been successfully applied against the closely related black pine aphid *Cinara cronartii* Tissot and Pepper, a pine pest originating in the USA and discovered in South Africa in 1974 (Kfir et al. 1985). Introduction of *Pauesia bicolor* Ashmead, a monophagous parasitoid (Hym: Braconidae) specific to *Cinara* spp. feeding on Cupressaceae, led to a population collapse of that aphid in that country. As a result, the International Institute of Biological Control (IIBC) conducted a search for natural enemies of this aphid (Allard et al. 1995) and successfully introduced *Pauesia juniperorum* Stary from western Europe into Malawi, Kenya and Uganda in a classical biological control project (Chilima and Murphy 2000; Rao et al. 2000; Day et al. 2003). This wasp with a black head, brown-black thorax, yellow legs and a yellowish abdomen, lays one egg per aphid. The mature parasite larva pupates inside the mummified aphid and hatches after six days. Kessy (1990) reported a total of six families of insects in four orders as natural enemies of the cypress aphid in Tanzania. In Kenya and Malawi the larvae of hover flies (Dip: Syrphidae) were frequently observed preying on the aphids. In Burundi, a decrease in aphid numbers was attributed to rains and the upsurge of an entomopathogenic fungus (Sabukwikopa and Muyango 1991).

Eulachnus rileyi (Williams) (=*Lachnus rileyi* Williams*; Eulachnus tauricus* Bozko*; Protolachnus bluncki* (Börner)). The pine needle aphid or powdery pine needle aphid was first described in Nebraska, USA (Williams 1910). Widely distributed in the holarctic region (Katerere 1984), it was found for the first time in the tropics in 1978 on various species of ornamental and plantation pine in Zambia (Löyttyniemi 1979). *Pinus patula* and *P. kesiya* are the most susceptible pines. In the meantime this aphid also occurs in Kenya, Malawi, South Africa, Tanzania, Zambia and Zimbabwe (Odendaal 1980; Owuor 1991; Murphy 1996).

As in its native range, this aphid is not a serious pest in Africa. All stages feed on the underside of needles of any age, causing mottling, usually on older needles and, at high rates of infestation, premature needle drop. Recruitment of new foliage usually outpaces damage caused. More conspicuous than the needle symptoms are heavy accumulations of honeydew and sooty mold during the dry season.

Adult pine needle aphids are 1.8-3 mm long, elongate insects that occur in both wingless (Figure 4-2A) and winged (Figure 4-2B) forms (Williams 1910; Blackman and Eastop 1994). Wingless adults are spindle-shaped, gray to light olive-brown and have dark-tipped, yellowish-brown antennae which are over half the body length. The cornicles are reduced to blackish rings. The aphid's whole body, including legs, is covered with long, black, bristly hairs and a dusting of bluish grey wax. The winged adults are of similar color and have red eyes. The broad, dark head has a central black stripe. The 6-segmented antennae are blackish-brown, the third segment being longest and pale at the base. The thorax is blackish and legs are black, with bases of the femora and the upper tibial halves yellow. The hind legs are very long and generally darker than the body. As in wingless forms, the entire body is hairy and

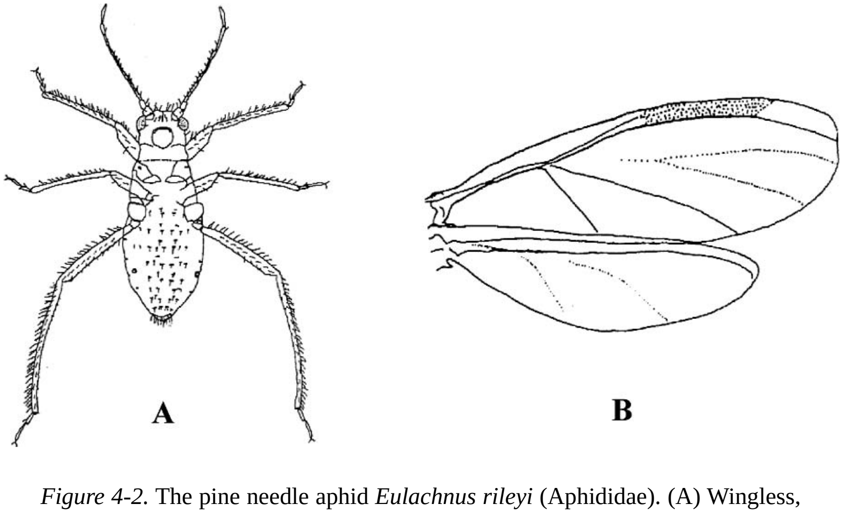


Figure 4-2. The pine needle aphid *Eulachnus rileyi* (Aphididae). (A) Wingless, viviparous adult and (B) wings of the winged form. (From Katerere 1984).

the cornicles are only a blackish ring. No eggs have been reported. There are four nymphal instars (Katerere 1984). Newly born nymphs or freshly molted aphids are dark, shiny olive-green, soon to be masked by whitish wax. In Zimbabwe, the duration for nymphal instars is about 48 hours for the first three and about 65 hours for the fourth instar.

Unlike in its native range, this species has a simplified life cycle in East Africa. It continuously produces overlapping generations of wingless, parthenogenetic, viviparous females, but winged females may also be found throughout the year. The population of this aphid typically experiences a rapid buildup after the rains, and a sharp drop at their onset, because numerous exposed aphids are washed off the host needles.

Several species of lady beetles, especially *Cheilomenes* spp. (Col: Coccinellidae), were observed to prey on this aphid, while hover fly larvae (Dip: Syrphidae) and lacewings (Neur: Chrysopidae) were also considered fairly important natural controls (Löyttyniemi 1979; Katerere 1984). Occasionally, the entomopathogenic fungus *Entomophthora planchoniana* causes epizootics (Katerere 1984).

Several minor forest tree aphids are briefly summarized in Table 4-1.

Adelgidae: Conifer Woolly Aphids. This entirely holarctic family consists of about 50 species in two genera, one of which became established in East Africa since the 1960s.

Pineus börneri (=Pineus pini) (Macquart). The classification of the pine woolly aphid was for a long time in question. In the literature it was mostly referred to as *P. pini,* the name under which it was originally identified after surfacing in Africa. Other authors called it *Pineus laevis, Pineus sylvestris, Pineus börneri, or* as belonging to the *Pineus strobi g*roup. Blackman et al. (1995) finally showed that the species causing problems from East and Central to southern Africa exhibited close affinity with *P. börneri,* an insect originally described from *Pinus radiata* in California, and thus should be referred to by that name. *Pinus laevis* (Maskell) is a synonym for *P. börneri*.

This aphid or its namesakes occur now on a wide range of pines in Australia, New Zealand and North America (Blackman and Eastop 1994). It was first found in 1962 in Zimbabwe and shortly afterwards in Kenya, the first of four species of exotic conifer aphids to eventually appear in sub-Saharan Africa (Brown 1969). In Kenya, the aphid was first discovered on grafts of *Pinus caribaea* from Australia which were being held in quarantine, but it may actually have arrived there earlier, as it was subsequently also found on several species of pine in the Muguga arboretum (Jones and Brown 1969). The aphid spread rapidly at the rate of 0.03-0.19 km per day (Urban and Kirsten 1995). Following two initial isolated outbreaks in seed orchards at West Kilimanjaro and at Sao Hill, it was eventually found in all pine plantations in Tanzania (Rwamputa 1987) and was later also discovered in Ethiopia, Malawi and South Africa (Murphy 1996).

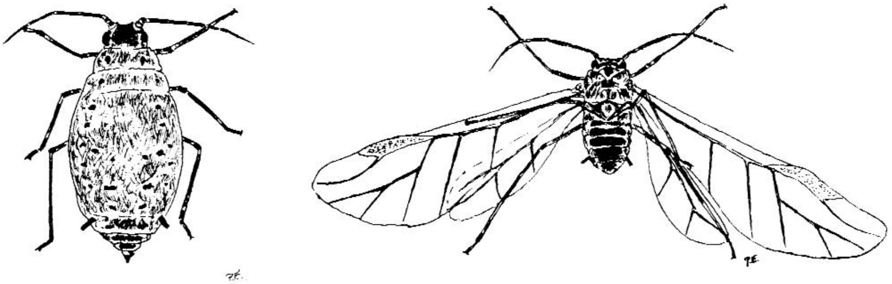
Table 4-1. Miscellaneous other tree aphids (Aphididae) occurring in East Africa.

Species	*Major Tree Hosts*	*Remarks*	*Reference*
Aphis gossypii Glov.	Annona, Citrus, Ficus, kapok, Rhus	Polyphagous cosmopolitan in warm climates. Vectors diseases	Eastop 1958
Neophyllaphis grobleri (=podocarpi) Eastop	Podocarpus spp.	Attacks any age causing needle curl; host-specific	Gardner 1957a; Eastop 1958
Paoliella echinata Eastop	Commiphora pilosa	Yellow nymphs and black and white alates	Eastop 1958
Stomaphis longirostris F.	Cupressus lusitanica bark	Gregarious feeder up to about 7 m	Gardner 1957a
Toxoptera aurantii (Boy.)	Gliricidia sepium	Polyphagous; near cosmopolitan	Eastop 1958
Toxoptera citricidius Kirk	Calodendrum capense, Teclea nobilis; Fagara macrophylla and other Rutaceae	Vector of "citrus quick decline"	Eastop 1958
Unipterus spp.	Commiphora; Combretum	Restricted to Burseracea or Combretaceae	Eastop 1958

According to Odera (1974), *Pineus* infests at least 39 species of pine, favoring *P. halepensis, P. massoniana, P. elliottii,* and *P. contorta.* Several species of other pines, *P. ayacahuite* and *P. strobus chiapensis,* are considered immune. The pine woolly aphid prefers to suck at the base of needles or in bark crevices of the current and previous year's shoots, but young cones may also be attacked. Symptoms include stunted and chlorotic needles, aborted buds, deformed twigs and premature needle drop. In heavier attacks, entire branches can be covered, which may lead to significant growth loss of *P. patula,* as determined in Kenya (Mailu et al. 1978), Tanzania (Rwamputa 1987; Madoffe and Austarå 1990) and elsewhere (Murphy 1996). Branch dieback is a frequent consequence and severely infested young and stressed pines may die (Odera 1974, Murphy 1996). While trees on a wide range of soils are attacked, population densities and damage is highest on trees growing on poor sites (Madoffe and Austarå 1993). Trees may recover but continue to look unhealthy (Massawe 1991). Infested cones may abort up to 25% of their seeds.

Several studies suggest that the life history of *Pineus* is similar in Africa and in Europe (Murphy et al. 1991). In Africa this insect does, however, occur exclusively on pines and reproduces only through parthenogenesis (Mills 1990). The more common form is about 1 mm long and wingless (Figure 4-3A), but occasionally some winged adults (Figure 4-3B) occur too (Esbjerg 1976). The insect itself is reddish or purplish brown, although that is not readily evident because of a white waxy cover. This bloom also covers the 0.3 mm long, yellowish-orange eggs, which surround the mother in clusters of 10-15. The first instar "crawlers" are about 0.4 mm long, move actively or are spread by the wind. Once settled, the insect remains in place as a stationary "feeder". In Africa the aphid is most abundant, and the damage is most pronounced during the dry season, while a marked population collapse tends to occur during the rainy season (Mailu *et al.* 1980; Mills 1990).

Attempts to curtail the pine woolly aphid by sanitation through a cut and burn approach proved unsuccessful. While several pesticides (Baygon, Thiodan and Teepol) were successful, gamma BHC was only partially so (Brown 1970; Odera



A **B**

Figure 4-3. The pine woolly aphid *Pineus börneri* (Adelgidae). (A) Wingless and (B) winged adult. (From Esbjerg 1976; reproduced by permission of P. Esbjerg).

1972; Massawe 1991). Costs for pesticide applications are, however, generally excessive, except for nurseries or seed orchards.

Strangely, *P. börneri* seems to have few pathogens and no parasitoids in its home range (Eichhorn 1972). As a result, attempts were made between 1970 and 1975 to control the insect biologically by the introduction of predators from Europe (Massawe 1991). Several species of *Scymnus* (Col: Coccinellidae) and *Leucopis* (Dip: Chamaemyiidae) failed to become established (Urban and Kirsten 1995). The predator *Tetraphleps raoi* Ghauri (Hem: Anthocoridae), introduced from Pakistan in 1975, did become established in Kenya and Tanzania (Day et al. 2003), but evidence concerning its impact is conflicting (Mailu et al. 1980; Mshiu and Kisaka 1983; Karanja and Alloo 1990; Massawe 1991). On the other hand, native predators are credited with achieving minor control. In a study in Kenya, nine species of native predators, most commonly lady beetles *(Exochomus* spp*.),* removed about 12% of an aphid population (Mailu et al. 1980). In some pine plantations at Sao Hill, West Kilimanjaro and Meru, other species of lady beetles (*Chaenomenes*, *Chilocorus* and *Rodalia)* were, however, credited with suppressing populations of the pine woolly aphid. Greatest mortality, especially of eggs and crawlers, resulted from being washed off their hosts by heavy rain (Mailu et al. 1980).

3.3.2. Superfamily Coccoidea: Scale Insects, Mealybugs, Coccoids

Morphologically and behaviorally, this superfamily of almost 7,500 species worldwide, is a strange group of insects, mostly between 0.5-5 mm long. They are monoto polyphagous phloem or parenchyma feeders. The more serious pest species usually have numerous hosts and are widely distributed throughout he world. However, there are exceptions. Some scale insects are highly host-specific, and some very damaging species have very limited distributions. Damaging levels are most common on ornamentals, in greenhouses, nurseries, orchards, and plantations of indigenous as well as exotic trees. Symptoms include discoloration of foliage, premature loss of foliage, twig dieback and death of entire plants. Although gregarious, individual scale insects of many species are difficult to detect, because of their small size, camouflage coloring and concealment in bark crevices or other hidden places. Others are betrayed by wax, honeydew, sooty mold and the presence of ants and other insects interested in the honeydew. The sooty mold may be serious enough to interfere with photosynthesis, supplementing damage resulting from the removal of tree sap.

The name scale insect derives from the protective shield under which the animals live during most of their life. Scale insects produce waxy or, rarely, resinous materials in specialized glands and secrete these through numerous pores to fashion their scales. The scale is either a more or less domed structure beneath which the insect resides on the host plant (e.g. in Diaspididae), or a layer of the material adhering to the insect's integument (e.g. in Coccidae). Adult male and female scale insects are drastically different. Males resemble tiny flies, as they only have one pair of wings. Females do not look like mature insects at all, but like a sac or a larva. They are

always wingless and other appendages are reduced or missing, except for the well-developed mouthparts. There is no clear separation between head, thorax and abdomen.

Sexual reproduction predominates, but the reproductive repertoire of the superfamily Coccoidea also includes parthenogenesis, some rare cases of hermaphroditism, and live birth, among other oddities. Adult females live for months or years, fixed to one location. Eggs are either laid under or close to the female's body, or in a waxy egg sac (ovisac) attached to her body. The ovoid, flat first instar nymphs are called "crawlers", as they have well-developed appendages and move around freely. They disperse autonomously or are carried by the wind, birds or other animals. Male scale insects are mostly haploid, undergo an unusual metamorphosis, and feed only in the first two instars. Of the four instars, one or two are pupa-like stages, during which the insect does not feed. Females go through two or three instars without the "pupa" stage. Depending on species and environmental factors, there are one to several generations a year.

At one time, control of scale insects relied on pruning and burning of infested material or various sprays involving mixes of oils, fats, petroleum and soap (Lindinger 1907). Control remains, however, difficult to this day, as scale insects are protected by waxy covers. Where affordable, the standard arsenal now includes systemic pesticides, insecticidal soaps or ultra-fine horticultural oils. Coccoids are often considered ideal targets for biological control, and indeed there are numerous examples of species that were formerly pests, but were brought under control by natural enemies, especially ladybird beetles (Col: Coccinellidae) (Figure 4-4). Biological control has failed, however, against some scale insect pests of particular crops in certain regions in spite of concerted and repeated efforts, and in some cases even when control by the same natural enemies was successful elsewhere.

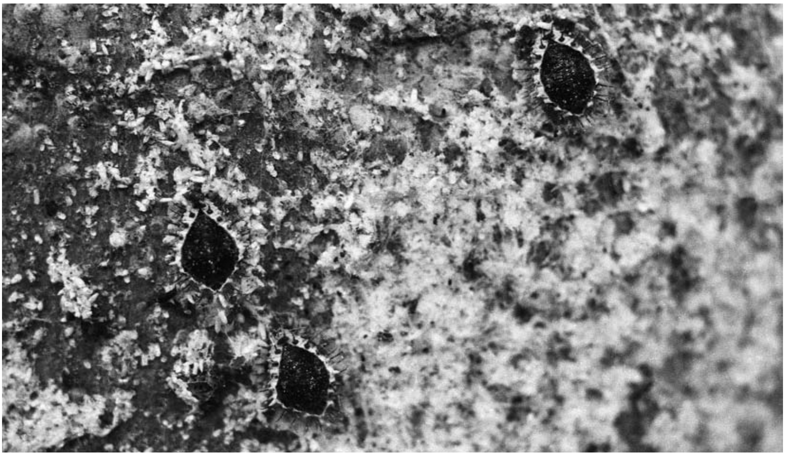


Figure 4-4. Pupae of ladybird beetles (Coccinellidae) amidst scale insect prey.

The taxonomy of scale insects is still controversial and synonymies abound (http://198.77.169.79/scalenet/scalenet.htm). The identification of species is largely based on morphological minutiae of mature females. East Africa has numerous indigenous and exotic species, as reflected in Lindinger (1912) and an extensive, 14-page listing of scale insects and their hosts, including many trees (Le Pelley 1959). Of the 20 or more families, however, only five or six contain species of greater concern or interest to forestry in East Africa.

Coccidae (=Lecaniidae): The family of soft scale insects includes over 1,129 species that are protected by a thick, but fairly soft layer of wax, which they secrete from pores in the integument. The appearance of adult females varies. Some are covered with a thin veneer of glassy wax, while others live under a thick dome of white or pinkish wax. Most have reduced legs, but otherwise resemble a sac full of 600-700 eggs. Males have one pair of wings, are usually red with smoky grey forewings and often have waxy appendages trailing behind. Honeydew, sooty mold and ants are standard accessories of coccids. While many soft scale insects are pests, a few are considered beneficial, as they are the source of a commercial wax. The following are among the more interesting genera and species of coccids relevant to forestry in Tanzania.

Ceroplastes (=Gascardia) spp.: *Wax Scale Insects.* There are nearly 150 species of *Ceroplastes*, mostly in warmer climates (DeLotto 1965). LePelley (1959) listed 18 species for East Africa, most on fruit trees, *Ficus* spp. and woody legumes. These insects tend to be around 10 mm across. They resemble an irregular ovoid blob of melted, white or pinkish wax. The flat, oval nymphs, surrounded by a fringe of waxy tendrils, feed on the veins of leaves for about a year, before switching to twigs. The red-yellow eggs are hidden under the insect. The African white waxy scale, *C. (=Gascardia) destructor* Newst., is now a cosmopolitan pest. As a result of its prolific production of wax, this scale was once explored for its potential as an export crop from German East Africa (Lindinger 1907). Reported under the name *C. cerifer* (Anders.) on *Acokanthera schimperi* at Amani, its simultaneous potential as a pest of citrus, fruit and shade trees may have brought this investigation to an end. There are three instars and one generation a year (Hill 1983). In *C. rubens*, nymphal development takes about 10-12 weeks and adults reach maturity in 4-6 weeks.

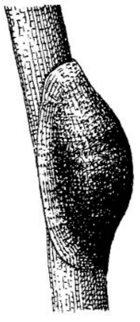


Figure 4-5. Female of the soft brown scale insect *Coccus (=Lecanium) hesperidum* (Coccidae). (From Weber 1930; reproduced by permission of Springer Science and Business Media).

Coccus spp. Many of the insects in this genus are of economic importance on cultivated plants in the afrotropical region (De Lotto 1957, 1965). Le Pelley (1959) listed 13 species for East Africa, mostly on fruit trees and ornamental hardwoods. The soft brown scale, *Coccus hesperidum* L. (Figure 4-5), a polyphagous and cosmopolitan species, was, however, also

documented on a conifer, causing slight damage to *P. radiata* in Kenya (Curry 1965a). This scale is light brown and flat when young. When older it turns darker, more domed and often displays a radiating pattern of stripes (Weber 1930).

Macropulvinaria inopheron (Laing) is a scale insect that occurs in severe outbreak populations on six multipurpose tree species (*Albizia schimperiana, A. falcataria, Calliandra calothyrus, Cassia spectabilis, Flemingia congesta* and *Robinia pseudacacia*) in Malawi (Mchowa and Ngugi 1994) and on several other crops elsewhere in Africa. Natural controls include the ladybird beetle *Chilocorus angolensis* (Crotch).

Saissetia spp. This genus includes at least eight species in East Africa (Le Pelley 1959; De Lotto 1965). From a forestry point-of-view, it may be the most important genus in this family, as the hosts include not only fruit and ornamental trees, but many wild and plantation species such as *Cassia, Chlorophora excelsa, Cinchona, Croton, Ceiba, Erythrina, Ficus, Gliricidia, Grewia, Hevea, Inga, Markhamia platycalyx, Syzgygium cuminii, Terminalia* and *Trema*. A single female of the almost cosmopolitan black scale insect, *Saissetia (=Lecanium) oleae* (Olivier), lays 1,000-4,000 eggs over 2-4 weeks (Hill 1983). Crawlers (Figure 4-6) hatch in 2-3 weeks and feed on the shoot tips and underside of leaves, while the adult females (Figure 4-7) prefer shoots and twigs (Weber 1930). Nymphal development takes about 2-3 months, unless interrupted by diapause. Total development requires about 3-4 months. Males are rare.

Figure 4-6. Crawlers amongst mature *Saissetia* sp. (Coccidae), infesting fruit of *Terminalia catappa.*

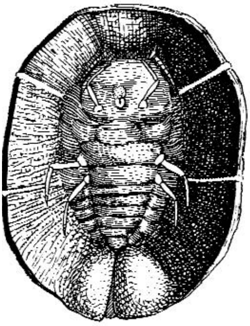


Figure 4-7. Female (ventral view) of the black scale insect *Saissetia (=Lecanium) oleae* (Coccidae) before oviposition. (From Weber 1930 with original from Berlese; reproduced by permission of Springer Science and Business Media).

Diaspididae: Hard or Armored Scale Insects. This family includes 2,369 highly specialized species of scale insects worldwide including many pest species in Africa. Adult females are featureless, flat insects about 1-2 mm across, with eyespots and antennae but no legs. They are hidden under a detached scale consisting of waxy secretions in which the shed skins of the first two instars are embedded. The shields of males often differ from those of females. Adult males are usually winged. Reproduction is either sexual or by parthenogenesis. This is among the few coccoid families that do not produce honeydew. Females undergo two instars before molting to the mature stage, while the males emerge as adults after the fourth molt.

Aspidiotus destructor (=transparens) Sign. The coconut or transparent scale insect is a pantropical pest primarily of coconut, but also found on numerous other crops, wild plants, palms and trees, including *Artocarpus, Celtis occidentalis, Cinnamomum, Citrus* spp., *Hevea brasiliensis, Mangifera indica, Manihot glaziovii, Pandanus, Persea americana, Psidium guajava, Syzygium cuminii* and *Terminalia catappa,* among others (Lindinger 1907; Le Pelley 1959; Hill 1983). Severe infestations of foliage, flowers and young fruit cause chlorosis or their premature loss. Infestation is most severe where rainfall is high.

In this species, adult female scale insects (Figure 4-8) are bright yellow and nearly circular, with a diameter of about 1.5-2 mm. They are covered with a delicate, semitransparent, slightly convex shield. The male scale insects are much smaller, oval and reddish and develop into two-winged adults. The tiny, yellow eggs are laid under the scale around the female. Incubation takes about 7-8 days. Nymphal development requires 24 days for males and more in females. The entire life cycle takes 31-35 days, allowing for about 10 generations per year.

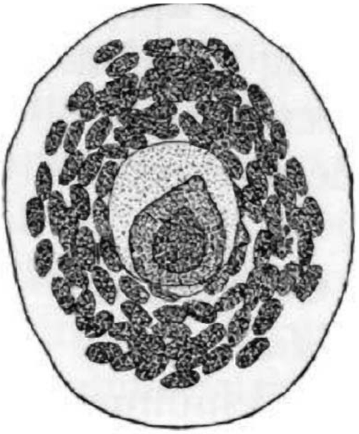


Figure 4-8. Adult female armored scale *Aspidiotus destructor* (Diaspididae). (From www.ento.csiro.au/aicn/system/c_1657.htm).

Another six species of *Aspidiotus* are listed by Le Pelley (1959), as occurring mostly on fruit trees. *A. hederae* Vall. does, however, also attack *Bauhinia*, *Caesalpinia* and *Cassia*. Many scale insects previously listed as *Aspidiotus* spp. have been subsequently assigned to other genera.

Control of *Aspidiotus* spp. with insecticides is generally difficult (Hill 1983). Parasites and predators are often effective antagonists, although serious outbreaks are possible even with heavy parasitism and predation. Ladybird beetles, especially *Chilocorus nigrita* (F.), are, however, often successful in combating this scale insect in various locations, including East Africa.

Aonidiella aurantii (Maskell): The California red scale insect is an equally common pest in East Africa, primarily on citrus trees. A close relative, the highly polyphagous oriental yellow scale insect, *Aonidiella orientalis* (Newst.), listed as occurring on cycads and castor bean in Tanzania, was recently involved in severe defoliation and sometimes death of neem trees, *Azadirachta indica,* throughout West Africa (Murphy 1998). As such it caused much concern and a biological control program was initiated in Nigeria.

Margarodidae (=Monophlebidae). The 442 species of these mostly tropical scale insects have sometimes been treated under separate family names (Ben-Dov 2005). Not all species are immobile scale insects, as certain stages may be equipped with legs and antennae. Some live underground, enabled by front legs modified for digging. During the dry season, pupa-like, legless resting stages occur in some species. Eggs are either deposited under a cover of wax or are collectively retained in an egg sac attached to the female. This family includes both the largest and the longest scale insect species in the world, the former occurring in East Africa.

Aspidoproctus spp. The mammoth scale insects occur throughout the Afrotropics and into southern Africa. At least seven of the 19 species of *Aspidoproctus* occur in East Africa (Le Pelley 1959; Ben-Dov 2005). The females represent the world's largest scale insect. They are, however, more curiosities than serious forest pests. Hosts include mostly legume trees such as *Brachystegia* spp. and *Delonix regia,* although some other species (*Grevillea robusta* and *Casuarina* spp.) may also serve as hosts (Picker et al. 1992).

The first visible appearance of these scale insects is a fluffy ball on the ground beneath affected trees (Newstead 1911). After emerging, the crawlers make their way to the nearest tree. The nymphs are oval, flat and crinkled (Plate 25). Adult females are dark-brown, oval, domed monstrosities, measuring up to 33 x 25 mm long and wide. They are usually covered with a fine whitish-yellow wax and may carry long wisps of wax filaments along the scalloped body (Figure 4-9). Each female produces 2,000-3,000 eggs, a fecundity shared with other margarodids. The males, with a wingspan of 5 mm, are red and also covered with a fine layer of wax. Crawlers are vulnerable to attack by ladybird beetles, while the still soft, pulpy nymphs are often eaten by

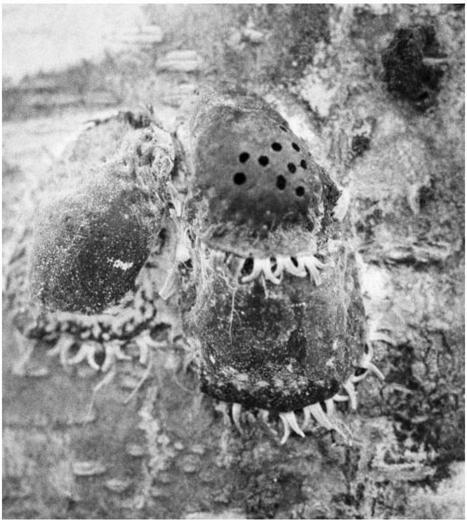


Figure 4-9. Mammoth scale insects, *Aspidoproctus* sp. (Margarodidae) on *Brachystegia* bark. One specimen is showing parasite exit holes. March, Morogoro.

birds (Newstead 1911). Adult females are often parasitized by certain flies (Cryptochaetidae) or wasps (Eupelmidae).

Icerya (=Pericerya) purchasi Mask. The cottony cushion scale insect, originated in Australia, but now occurs throughout the warmer parts of the world where it is mainly a serious pest of citrus trees, but also attacks mango, guava and various acacias, the original host genus (LePelley 1959; Ben-Dov 2005). Foliage of heavily infested young shoots and young trees suffer chlorosis and premature leaf drop and are often killed. Honeydew and sooty mold are secondary problems. In the 1950s, serious damage to *A. mollissima* plantations occurred in the West Usambaras, and on *Pinus palustris* at Sao Hill (Mshiu 1976; Mshiu and Kisaka 1983).

The winged males of *I. purchasi* (Figure 4-10A) are rare; females are also rare as most individuals are self-fertilizing hermaphrodites (Weber 1930). These mottled, light-brown scale insects are usually found on twigs and shoots. More conspicuous than the insects themselves are the large, white, fluted egg sacs (Figure 4-10B) that account for this insect's alternate name, fluted scale insect. The sacs contain from 100-1,000 red, oblong eggs that hatch within a few days or up to two months, depending on environmental conditions. The three nymphal instars are shiny, reddish. At first they assemble along the midrib under the leaves, before moving to the stems as they mature.

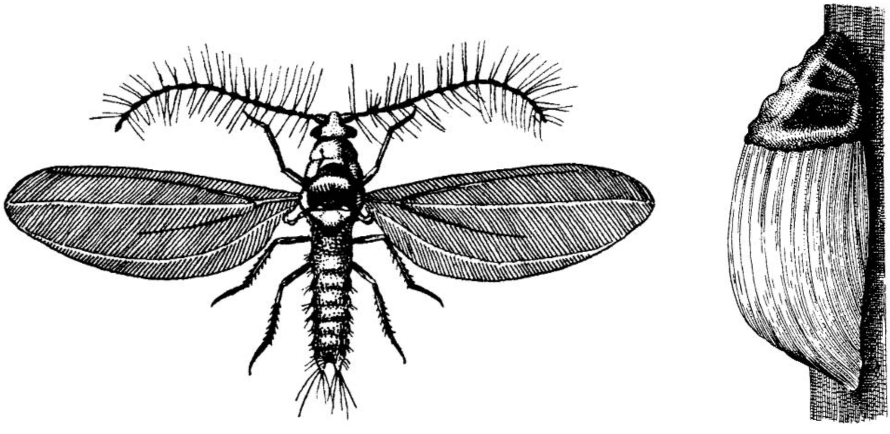


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Figure 4-10. The cottony cushion scale insect *Icerya purchasi* (Margarodidae). (A) Male and (B) female. (From Weber 1930 with original from Berlese; reproduced by permission of Springer Science and Business Media).

This scale insect was brought under control by the lady beetle *Rodalia cardinalis* Muls. and by *Cryptochaetum iceryae* Will. (Dip: Agromyzidae), both introduced to Tanzania from South Africa in the 1950s (Garder 1957a; Mshiu and Kisaka 1983). *R.cardinalis* had already previously attained prominence, when it saved the California

citrus industry from *I. purchasi*. Tanzania also harbors indigenous species of *Rodalia* and at least seven species of *Icerya* (Ben-Dov 2005).

Orthezidae: Members of this small family of about 155 species of so-called ensign scale insects have mobile nymphs and adult females with well-developed appendages. Only one exotic, the jacaranda or lantana bug, *Insignorthezia (=Orthezia) insignis* (Browne), is of interest to forestry in East Africa (Hill 1983) This insect is mainly a pest of coffee, but also feeds on foliage, shoots and fruit of citrus and the weedy, exotic shrub *Lantana camara,* among many other herbaceous and woody hosts (Gardner 1957a; Le Pelley 1959). It caused serious damage to ornamental *Jacaranda mimosiflora* in the East African Highlands (Gardner 1957a).

Female Jacaranda bugs are 1.6 mm long without, and about 4.5 mm long with egg sac. Nymphs and females have three naked, black-green stripes running the length of the back, alternating with rows of white, waxy plates. They produce prolific amounts of honeydew. There are several generations a year which reproduce mostly by parthenogenesis.

The outbreak in East Africa was short-lived due to the highly successful introduction of a ladybird beetle, *Hyperaspis pantherina* Fürsch, from Hawaii to Kenya in 1945, Uganda in 195? and Tanzania in 1953. Releases at Moshi are claimed to have saved jacarandas in that area (Hill 1983). This beetle recently scored another success, when specimens collected in Kenya were released in St. Helena to save this country's national tree, the threatened and endemic gumwood, *Commidendrum robustum* (Fowler 1996). By the time the beetle was released in 1993, *I. insignis* had already killed one fifth of the 2,000 remaining specimens of this rare tree. This is apparently the first instance, where a plant was saved from extinction by biological control of a pest.

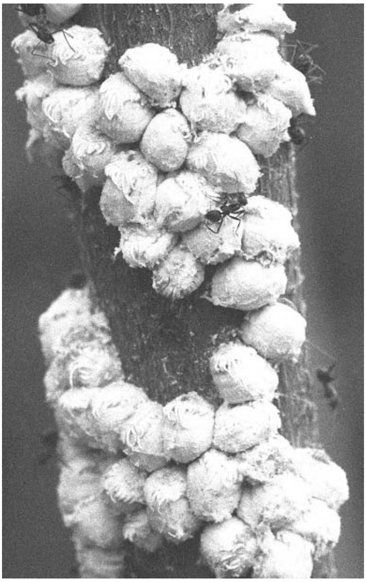


Figure 4-11. Colony of a mealybug (Pseudococcidae) with attendant ants seeking honeydew.

Pseudococcidae: Mealybugs. Along with the Margarodidae and Orthezidae, this family is among the least specialized of the Coccoidea. Most females have legs and antennae and retain limited mobility until egg development. The body segmentation of these small insects of less than 5 mm is visible through the outer wax layer. In warmer climates there are up to six generations per year. Mealybugs feed on all plant parts, including roots. Honeydew, sooty mold and ants are usually associated with them (Figure 4-11). Among the almost 2,000 species,

there are many pests, including the cassava mealybug, *Phenacoccus manihoti* Matile-Ferrero. In the 1970s, this South American insect developed as a major threat to cassava in Africa until a host-specific parasite was introduced in Nigeria 1981, leading to a population crash of this menace within months. Only the following mealybugs are of concern to East African forestry.

Nipaecoccus viridis (Newst.): The Asian pink, spherical or lebbeck mealybug has 12 different scientific names, including most commonly *Dactylopius viridis* (Newst.), *N. vastator* (Maskell), *Pseudococcus filamentosus* Green and *D.perniciosus* (Newst. & Willcocks), and a multitude of common ones, causing much taxonomic confusion (Sharaf and Meyerdirk 1987). It was reported in at least 27 countries in the subtropics and tropics, including sub-Saharan Africa (Eritrea, Ethiopia, Kenya, South Africa and Tanzania), and from the Near East through Asia to as far as Japan and Oceania. There is still disagreement concerning its origin in Asia vs. Africa.

This mealybug once caused a serious outbreak on ornamental trees in Dar es Salaam (Kränzlin 1913). The most heavily infested host was *Albizia lebbeck*. The branches and fruits of these trees were completely covered with a white-woolly mass, honeydew and sooty mold, and eventually the foliage, flowers and fruits curled, turned chlorotic, stunted or shed prematurely. In other cases, wilt and dieback have been reported. This insect occurs on at least 96 species of plants in 73 genera and 34 families, including acacias, *Casuarina*, *Leucaena leucocephala*, *Pithecelobium saman*, *Pongamia glabra*, kapok, mulberry, citrus, mango, and *Ziziphus*. During the outbreak in Dar es Salaam, *Terminalia* proved immune, while *Poinciana pulcherrima*, tamarind and eucalypts, among others, were listed as resistant.

This mealybug reproduces sexually and by parthenogenesis. The oval, somewhat flattened females are spherical, 2-3 mm long insects. They are covered with a thick layer of white to pale yellow wax and have 7-segmented antennae and relatively well-developed legs. The body is greenish-purple, dark brown or black. The white egg sac is hemispherical and consists of flocculent wax. It contains several hundred eggs that are laid in 21-37 days and hatch in about 10 days. The adult male is an oblong, slender, light brown insect with a caudal filament. The antennae are 10-segmented, the eyes are large, the front wings are well developed, but the hind wings and mouthparts are degenerated. There are five instars for the males and four for the females. Nymphal development takes 19-20 days. Depending on the season, different host parts are attacked, including branches, twigs, shoots, leaves, flower buds, fruits and roots. Reproduction continues throughout the year, resulting in multiple, overlapping generations.

Lengthy periods of moisture or drought depress this bug. High relative humidity adversely affects the egg hatch, while high temperatures affect all stages. Over 77 enemies have been reported, of which about 13 are highly effective, including *Anagyrus dactylopii* (Hym: Encyrtidae) from Asia, which brought the bug under control in Hawaii (Sharaf and Meyerdirk 1987).

Dysmicoccus brevipes (Ckll.): The pineapple mealybug is a pantropical insect best known as a vector of the mealybug wilt virus that causes “quick wilt”, a serious root rot of pineapples. Hosts include a number of other agricultural crops and several fruit trees, including palms and *Pandanus* (Le Pelley 1959; Hill 1983). In 1994, heavy infestations of this insect were observed for the first time on *Casuarina equisetifolia* in coastal Kenya, causing 20% mortality in one location (Ciesla 2000). As this Australian tree grows well on sandy sites in ocean-influence zones and makes an attractive substitute for mangrove building poles, it is a popular plantation species along the East African coast. *D. brevipes* usually lives in colonies underground, but some venture above. These aerial individuals are mostly hidden at the base of leaves. Heavy infestations cause root necrosis and discoloration. Previously, another mealybug, *Pseudococcus obtusus* Newst., had been reported as heavily attacking the lower branches of *Casuarina* growing on poor soil in Zanzibar (Mansfield-Aders 1919/20).

Planococcus (=Pseudococcus) citri (Risso): Citrus or common mealybug. This is another pantropical pest feeding on the shadowy parts of various crop trees and the roots of *Combretum* and *Indigofera* (Hill 1983). The aerial form occurs on leaves, twigs and the base of fruits. Sap loss, toxins and sooty mold often conspire to cause drought-like symptoms and occasionally the death of hosts. Roots are often stunted and encased in a crust of greenish-white mycelium under which the insect can be found. Females are oval, flat and carry 17 pairs of spiny extensions along the side of the body (Figure 4-12F) (Weber 1930). Males (Figure 4-12E) are winged and appear before the females.

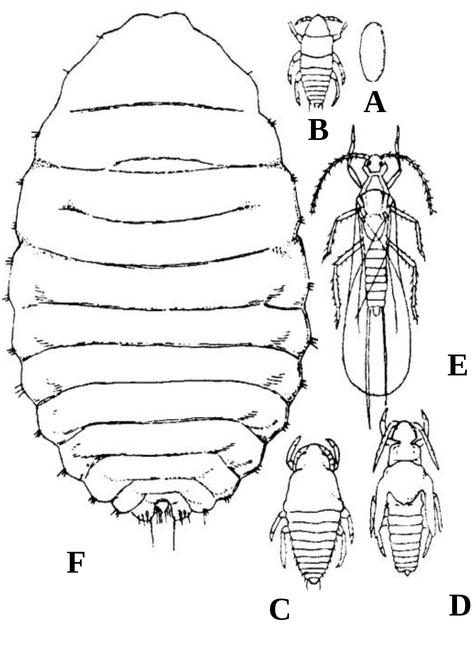


Figure 4-12. The common mealybug *Planococcus (=Pseudococcus) citri* (Pseudococcidae) showing (A) egg, (B) larva, (C, D) nymphs of male, (E) adult male and (F) adult female, all drawn to scale. (From Weber 1930 with original from Berlese: reproduced by permission of Springer Science and Business Media).

Maconellicoccus hirsutus (Green) (=*Spilococcus perforatus* deL.), a cosmopolitan pest on numerous hosts, was observed on small transplants of teak in a Moshi nursery (Gardner 1957a), while *Rastrococcus (=Phenacoccus) iceryoides* (Green) was considered one of the most important pests of kapok and cotton in Tanzania, causing leaf drop and twig dieback (Morstatt 1942).

Eriococcidae: Insects in this family, called felt scale insects, are often considered belonging to the mealybugs. Only the felted pine coccid, *Eriococcus araucariae* Maskell, was reported causing slight damage to *Araucaria* spp. in Kenya (Curry 1965a).

3.3.3. Superfamily Psylloidea: Jumping Plantlice

Most of the about 2,500 species in this group occur in the world's warmer zones. They are from 0.2-8 mm long and resemble jumping mini-cicadas with multi-segmented antennae. They feed on phloem, xylem and mesophyll of hardwoods, many being specific for certain hosts and host parts. The dorso-ventrally flattened nymphs are free-living or protected in galls or lerps, the latter being scale-like covers built from excrement. Damage to hosts results from sap removal, toxins or the vectoring of disease. Signs and symptoms include galls, chlorosis, stunting, wilting, premature shedding of foliage and honeydew.

Jumping plantlice reproduce sexually and there may be several generations per year. Eggs are stalked and inserted into tree tissues.

Although the citrus psyllid, *Trioza (=Spanioza) erytreae* (DelG.), of the family Triozidae occurs on *Erythrina abyssinica*, it is foremost a pest of citrus and will thus not be given more than this mention. As a result, only representatives of two of the six families of jumping plantlice, which have special interest to East African forestry will be discussed to a greater extent.

Phacopteronidae. This small family occurs in conjunction with Meliaceae throughout the tropics. *Pseudophacopteron (=Phacosema) zimmermanni* Aul. was observed at Morogoro, Kimboza and Moshi in Tanzania, as well as in Uganda, often causing severe galling on the young foliage of seedlings of *Khaya* (Figure 4-13) or on succulent shoots at the base of larger specimens. Based on shed leaves fallen from mature *Khaya*, it appears that galls also occur in the crowns of these trees. The hypertrophies are of variable, mostly globular shape. They occur randomly over the leaf blades and are about 0.5 cm in diameter, consisting of a closed hollow portion on the upper leaf blade and one with a small opening on the opposite side. On the youngest leaves, gall density can be severe enough to dwarf and distort the leaflets with conglomerates of galls (Aulman 1911). In Morogoro, galls are most conspicuous in early April, at which time the 0.3 mm long nymphs emerge from the galls through the opening on the lower side of leaflets and instantly molt into adults. Adults escape by hopping. The biology of this insect is still unknown. Another species of

Pseudophacopteron damages *Aucoumea klaineana* in nurseries and young plantations in West Africa (Brunck 1965).

Figure 4-13. Sapling of *Khaya nyasica (= K. anthotheca)* with leaf galls caused by *Pseudophacopteron zimmermanni* (Phacopteronidae). Early April, Morogoro.

Psyllidae. This family includes several serious pests of trees that are of great importance in East Africa as well as a number of other countries. This explains the fact that relatively much information concerning these insects has accumulated.

Heteropsylla cubana Crawford (=*Rhinocola incisa* Sulc.): The leucaena psyllid attained prominence in conjunction with the culture of *Leucaena leucocephala*, a small tree, often touted a “miracle tree” and occasionally reviled as a weed, which is an extremely productive legume native to tropical America. Being planted in over 130 countries, it may now be the most widely used multi-purpose tree legume in agroforestry throughout the (sub)tropics. Its greatest uses are for fodder production, poles and woody fuels in conjunction with alley cropping and related systems.

During the first decades following its inclusion in many large-scale plantings throughout the tropics, one of leucaena’s many attractive features was a relative lack of pests (Pound and Martinez Cairo 1983). Unfortunately, the leucaena psyllid followed its host from the native range in Central and South America and within little more than a decade swept westward halfway around the globe. In the early 1980s, the psyllid had arrived in Hawaii and within a few years had started spreading into the Asia-Pacific region. By mid-1985 it had moved throughout the Pacific and 1986 saw its arrival in Australia, Indonesia, the Malay Peninsula, Vietnam and all of Thailand. It surfaced in Sri Lanka in 1987, in China, Myanmar and India in 1988, the island of Reunion in 1991, and in Madagascar in 1992. The same year, it arrived on

the African mainland on the Kenyan and Tanzanian coasts (Reynolds and Bimbuzi 1992). The psyllid's explosive spread, which can only be explained by its behavior as aerial plankton, continued on this continent, at times gaining 350 km in little more than three months. By 1998 it was also found in Burundi, Ethiopia, Malawi, Mozambique, Rwanda, the Sudan, Uganda, Zambia and Zimbabwe and continued to spread (Murphy 1998).

The leucaena psyllid's aggressive advance justifiably caused major alarm in the agroforestry community and prompted a significant international research effort (Anon 1990; Beldt and Napompeth 1992). Ultimately, however, this initially fulminating epidemic ran its course wherever the insect had invaded. After several years of devastating impact, the crisis is now under control. The typical pattern of new infestations, as first observed in the Asia-Pacific region, was characterized by a sudden and dramatic decline or dieback of leucaena for about a full year, followed by a second year peak of the psyllid. During the third year, the pest tended to be mostly absent and its effect on leucaena was greatly minimized. It subsequently spread out in weak, seasonal infestations from isolated, scattered population pockets (Beldt and Napompeth 1992). In its native range, the psyllid fluctuates widely in time and space, and damage is rarely noticed (Reynolds and Bimbuzi 1992). Near the equator, the psyllid is generally found at low densities. Its population dynamics relate to a definite optimum temperature range, the availability of growing shoots and the status of its natural antagonists. Extreme wet and dry periods suppress populations of this psyllid.

In Tanzania, high populations and serious damage coincided with the beginning of the dry season, when new shoots were developing, especially on pruned leucaenas (Kisaka 1995; Madoffe and Massawe 1995). Both the nymphs and adults cause damage by sap-feeding, which is confined to younger leaves (Plate 26), terminal shoots and inflorescences. Depending on the severity and duration of the attack, tissues affected are stunted (Plate 27) or wilt and the trees may fail to flower and seed. Partial or complete defoliation (Plate 28) may result, leading to growth reduction and mortality especially in younger trees and those grown in less than optimal conditions. Honeydew is a secondary problem. Fresh foliage on new shoots may be deformed and chlorotic, but even completely defoliated trees often recover. Damage is most severe on *L. leucocephala* and some varieties of *L. diversifolia*. In Tanzania, *Faidherbia albida*, a native legume that is also of great interest in agroforestry, may also be attacked by *H. cubana* (Madoffe and Massawe 1995). In its native range, the psyllids not only feed on *Leucaena* spp. but also on the related legume genera *Mimosa* and *Piptadenia* (Burckhardt 1986). In Hawaii, the insect is also known to damage *Albizia saman*, another legume tree, and adults were found on *Delonix regia* (Sorensson and Brewbaker 1984; Napompeth and MacDicken 1990).

The adult leucaena psyllid (Figure 4-14A) resembles a miniature cicada (Donaldson 1986; Yang and Fang 1986). It has a total length of up to 2.2 mm including the transparent wings and of 1.3-1.7 mm without wings; males generally are on

the smaller side. The antennae are dark and about 1mm long. The insect is whitish green to yellow greenish or yellowish brown, with dark eyes and dark tips to the legs and the mouthparts. A narrow, dark, transverse line is often present between the head and the thorax or body. When disturbed, adults jump. The nymphs (Figure 4-14B), in shades of yellow, resemble the adults except that they are flattened, elongate-oval, have pale brown antennae, dark wing pads and in the late instar develop characteristic brown spots and red eyes.

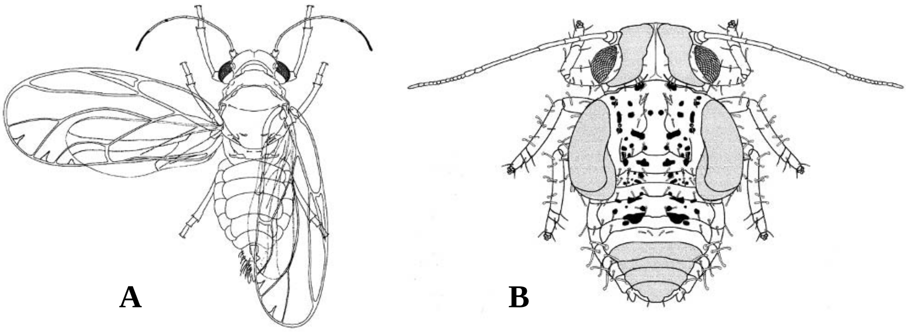


Figure 4-14. The leucaena psyllid *Heteropsylla cubana* (Psyllidae). (A) Adult and (B) nymph. Specimens drawn originated on Oahu Island, Hawaii. (P. Schroud).

Most observations concerning the psyllid's life cycle were obtained in various locales in the Asia-Pacific region, for which reason some of the reports differ. In general, the psyllid was found to be a multivoltine insect with a short life span. According to most reports, females live from about two weeks to possibly a little longer than a month, while males last little more than one week. The adults are day-active, the male more so than the fairly sedentary female. Pairs copulate repeatedly, for minutes at a time and at several minutes apart. One to three days later, each female starts laying as many as 60 eggs per day, for an average total of 200-400. The eggs are yellow, oblong and at one end carry a filament. They are attached by a petiole to the upper surface or between developing leaflets on terminal shoots. Nymphs hatch after 2-3 days. The number of instars reported is generally five, but four have also been claimed. The first four instars develop in 2-3 days each, the last one in 2-5 days. It takes 10-20 days to go from egg to adult stage.

The psyllid is easily controlled by various systemic and broad-spectrum insecticides, which give effective protection for up to three weeks (Rao 1995), although their use, in most circumstances, is neither economical, nor ecologically justified or practical for small farmers in Africa. Sprays of 5% neem seed powder extract were not effective against psyllids at high population densities.

Ultimately, classical biological control and tree-breeding programs emerged as most successful and feasible strategies for the management of leucaena psyllids (Napompeth and MacDicken 1990; Day et al. 1995). Extensive genetic trials in

Hawaii, involving more than 500 varieties and all 13 species of *Leucaena,* showed certain selections and inter-specific hybrids to be tolerant or resistant to attack by the psyllid. In particular, hairy strains and hybrids involving *L. diversifolia* showed high levels of resistance to the psyllid. Strain K 636 of *L. leucocephala,* however, stood out, because it not only proved to be among the most psyllid-resistant varieties but at the same time was a vigorous grower.

Natural enemies, notably predators and entomopathogens of the psyllid, were frequently observed in various places, including Africa (Ciesla and Nshubemiki 1995). They routinely included predacious lady beetles (Coccinellidae), hover fly larvae (Syrphidae), and several groups of more general predators. A search by the International Institute for Biological Control (IIBC) for natural enemies in the psyllid's home range, yielded two coccinellid predators from Mexico, *Curinus coeruleus* Mulsant (Plate 29) and *Olla v-nigrum* (Mulsant), as well as two hymenopterous parasitoids, *Psyllaephagus yaseeni* Noyes (Encyrtidae) (Plate 30) and *Tamarixia leucaenae* Boucek (Eulophidae) from Trinidad. The two beetles had previously been imported to Hawaii for the control of some other sap feeders and became abundant and effective predators when the leucaena psyllid made its appearance in those islands in the 1980s. Because of this, they were subsequently introduced to several other locales as the psyllid spread (Ciesla and Nshubemuki 1995). The two parasitoids were also researched and released in various places (Beldt and Napompeth 1992). Based on experience gained in Asia and given their high degrees of host-specificity, the wasps were singled out as superior candidates for introduction into Africa (Boucek 1988; Day et al. 1995). Indications are, however, that the parasitoids are only having a minor effect on this continent (Rao et al. 2000). In many places during rainy seasons, entomopathogenic fungi were repeatedly observed to reach epidemic levels in populations of the psyllid (Reynolds and Bimbuzi 1992; Ciesla and Nshubemiki 1995), very effectively supplementing the partial impacts of native and exotic predators and parasites. The combined effect of these biocontrol agents with resistant leucaena stock ultimately accounted for the control of this pest in Asia (Beldt and Napompeth 1992), as well as in Africa.

Phytolyma spp.*: Mvule Gall Bug*. Two timber species in the family Moraceae, *Chlorophora (=Milicia) regia* and *C. excelsa,* are generally referred to as African teak, as iroko or odum in West Africa and as mvule in East Africa. These trees are highly valued for their attractive wood, which is naturally resistant to insect attack and decay, and thus in demand for ornamental and structural applications, including beehives. Unfortunately, seedlings, saplings, and coppice shoots of mvule suffer serious damage from *Phytolyma* spp. These insects exclusively attack *Chlorophora* spp. throughout most of their range, i.e., tropical rain and semi-deciduous savanna forests from West through Central to East Africa, as far as northern Zambia, Malawi and Mozambique. The insect is apparently absent in Zanzibar (Jones 1957), but otherwise is considered the biggest single obstacle to the establishment of plantations of mvule. Major attempts at plantation culture of *C. excelsa* were begun at Pugu in German

East Africa (Vosseler 1906a,b), then again in British colonial days at the same site as well as at Mogo, Rau, Mtibwa, Kileo and the Rondo Plateau (Jones 1957). Originally viewed as one species, *Phytolyma lata* Scott was later considered a complex of different forms (White and Eastop 1964). Even today, no general agreement exists concerning distinct species. The East African population of this insect is sometimes referred to as *P. fusca,* while *P. lata* Walker and *P. tuberculata* (Alibert) are applied to the psyllids attacking *C. regia* in far western Africa (Wagner et al. 1991).

The damage done by *Phytolyma* involves four types (Vosseler 1906a,b). Of least concern is the loss associated with sap feeding. Somewhat more serious are the loss of growth substance deflected onto gall production, as well as the deformation of stems. Most serious is the scarring and rot resulting from extensive gall formation, which can lead to twig mortality, dieback and complete loss of young trees up to three years of age. While older trees may have a few galls on newly flushed leaves and flowers, they generally not seriously affected by the mvule gall. These trees do, however, serve as reservoirs, from which the insect initiates attacks on succulent tissues of the terminals of juvenile trees or coppice sprouts during the growing season. Galls are light to yellow green and are of various shapes depending on the tissues involved (Vosseler 1906a). Single galls tend to be bulbous on older twigs, flat and scaly on younger ones, globular on leaf petioles and blades, and semi-globular to elliptical on shoots. They often coalesce into grotesque clumps of galled tissue with only parts of leaves emerging from the gall mass. Even galled flowers occur (Jones 1957). Single galls contain 1-5 nymphs, often representing different instars, while chamber systems, associated with gall conglomerates, may contain more individuals. Ageing galls eventually rupture like opening flower buds and allow their inhabitants to escape. They subsequently dry out or, more seriously, start rotting from a fungus (*Fusarium* sp.*),* which may spread to neighboring tissues.

Mvule gall bug development takes from 2-4 weeks (Vosseler 1906a,b; Cobbinah 1990). Adults are present throughout the year. During the deciduous stage of the host, they survive in low numbers on woody twigs, where they hide well-camouflaged in leaf scars and old, galled cavities. Females first lay a batch of about 100 eggs, usually during early morning hours, then, in short succession, another two batches of about the same number each. The eggs (Figure 4-15A) measure about 0.287 x 0.115 mm, are white to yellow, oval, laterally compressed and attached to the substrate by a short, sturdy stalk. The forward point of the egg gives rise to a long, light-colored thread that snakes backwards, often sticks to the opposite end of the eggs and then reorients forward, thus resembling a handle. On dormant tissues, eggs are found between hairs of petioles, on twigs, next to buds, at the basis of buds, or between bud scales in rows of 4-10. On fresh shoots they are distributed randomly over stalks or leaf blades, often in loose groups of 20-30. As long as succulent tissues are available, reproduction continues, ultimately resulting in all stages being present simultaneously.

Nymphs normally hatch after about 8 days, but only leave the eggshell if young, succulent tissues are available in the neighborhood. The first instar (Figure 4-15B) is

yellow to white, round and flat and greatly resembles the crawlers of scale insects. It probes in host tissues initiating gall formation, which, in a matter of about two days, encloses and effectively traps the nymph. Hints of wing buds become visible in the second instar. The third instar turns milky white, has bright red eyes, and sports blackish to brownish wing buds and large dots on the back which become pronounced starting with the fourth instar. Vosseler (1906b) tentatively claimed six instars, but Jones (1957) insisted on five. Mature nymphs are about 2.5 mm long (Figure 4-15C). Small, waxy exudations can be found near the tip of the abdomen of nymphs of all instars.

Development from first instar to adult takes about 2-3 weeks or more. Adults (Figure 4-15D) hatch in the gall and are often trapped there temporarily until the gall ruptures. They are 3-4 mm long and both sexes look similar, the male being slightly thinner. Their color is a light or yellowish brown and they hold their translucent

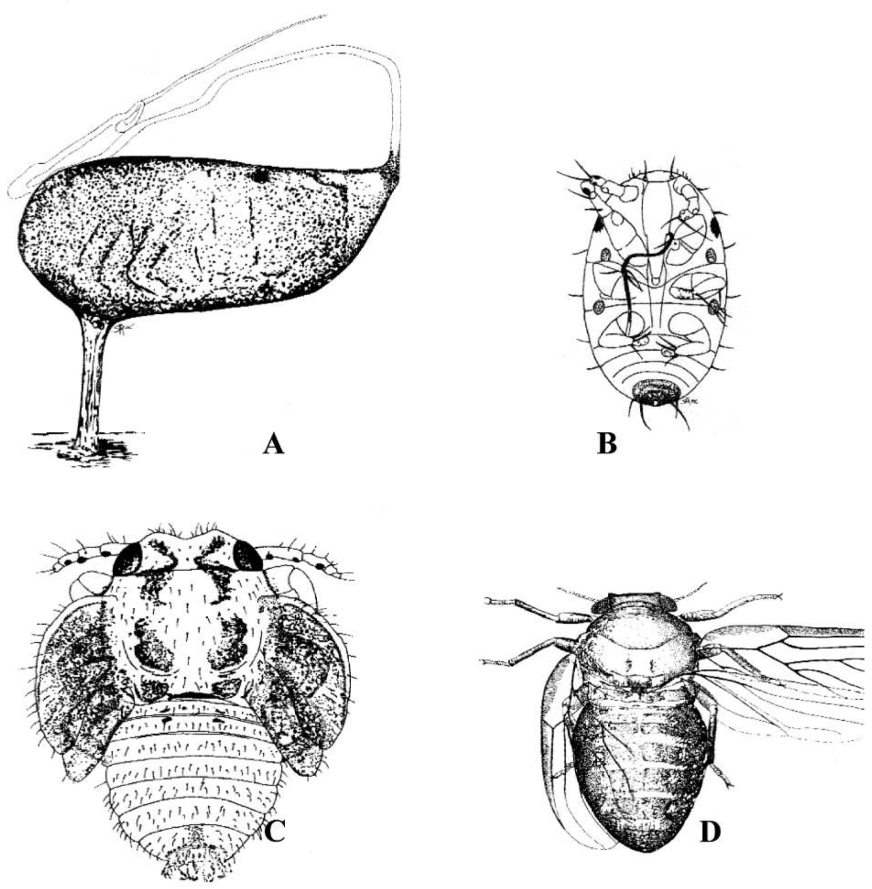


Figure 4-15. The mvule gall bug *Phytolyma* sp. (Psyllidae). (A) Egg, (B) ventral view of first instar nymph, (C) mature nymph and (D) adult. (Redrawn from Vosseler 1906b by P. Schroud)

wings roof-like, resembling a miniature cicada. Their heads, 10-segmented antennae and legs are brownish-black, with the femora darker than the more distal segments. The abdominal tip of females exhibits an ovipositor, while males are characterized by a fork-like mating clasper. The mid femur of males is equipped with a large spike and a smaller tibial projection. Both sexes have well-developed hind legs which allow hopping. Despite wings, there seems to be little inclination to fly. Mating usually occurs in the early morning hours, side by side, the modified mid leg of the male restraining the female.

Several attempts to investigate and manage mvule gall bugs in different parts of their range initially took place in the early 1900s (Vosseler 1906a,b), then again in the 1930s (Harris 1936b) and in the 1950/60s (Willan 1963; White 1966, 1968). Attempts generally resulted in the resigned admission that no economically feasible solution for control was apparent (White 1968). Various pesticides applied against the psyllid or the fungi causing gall rot proved impractical, as the insect is shy and hidden (Willan 1963). Pruning and burning of galled tissues was also dismissed as doing more harm than good. Various endoparasitic wasps, including *Aprostocetus* spp. (Eulophidae) and *Psyllaephagus perendinus* (Encyrtidae), though occasionally fairly abundant in various parts of mvule range, proved insufficient as natural controls. Several silvicultural experiments involving shelterwood regeneration or sanitation around nurseries were also disappointing (Willan 1963).

Now, a concerted effort involving numerous cooperators from several agencies, including research institutes and academic institutions in the USA, Europe and Africa is underway in West Africa (Pattie 2001). In a multi-pronged approach, this international consortium hopes to tackle the *Phytolyma* problem through an integrated pest management approach, involving biological, chemical, genetic and silvicultural dimensions. Most promising in this endeavor may be exploitation of the high genetic variability to gall bug attack between and within populations of *Chlorophora* spp., which had first been observed by Vosseler (1906b) and which is presently being tested in provenance and progeny trials in West Africa (Ofori et al. 2001). As during the dry season significant differences in the degree of parasitism of gall psyllids are found among three genotypes of *Chlorophora*, integration of biological control and host plant resistance was suggested as a possible solution (Bosu et al. 2001). Low density planting of mvule, in mix with other species, may also be a promising approach (Nichols et al. 1999). This has already been documented in East Usambara, where levels of psyllid infestation were kept tolerable in plantations consisting of a mix of 20% *C. excelsa* and 80% *Maesopsis eminii* (Schaefer and Siva 1990). This procedure emulates natural conditions, where mvule is typically associated with other tree species and at low densities generally suffers little from attack by the mvule gall bug.

Ctenarytaina eucalypti (Mask.). The blue gum psyllid, a native of Australia, was already introduced into New Zealand in the late 1800s. It subsequently surfaced in various countries in Europe, North and South America, Asia and in South Africa

(Hodkinson 1999). This psyllid was recently confirmed in Burundi, Ethiopia and Tanzania (Ciesla et al. 1996). Damage, caused by nymphs and adults, includes honeydew, distortions and wilted foliage mostly at the tips, followed by leaf drop, dieback of branches and growth loss on *Eucalyptus globulus, maideni, nitens* and *gunnii,* among others (Ciesla et al. 1996; Hodkinson 1999). Eggs are laid in masses near developing buds. The nymphs are pale yellow with dark patches of purple. They are sheltered underneath waxy filaments or lerps. The adult psyllids, which are strong fliers, are 1.5-2 mm long. The body is dark purple with transverse yellow bands on the upper and lower abdominal surfaces and on the underside of the head and thorax. The wings are grayish-white. The parasitoid *Psyllaephagus pilosus* Noyes (Hym: Encyrtidae) was successfully released in California and Europe for biological control of this pest (Hodkinson 1999).

The blue gum psyllid must not be confused with the newly described blue gum chalcid, *Leptocybe invasa* Fish. & LaS. Although this insect is a wasp (Eulophidae), and thus does not belong to the Hemiptera, it will be briefly discussed here, because it is only a matter of time before it will surface in Tanzania, because of the similarity of its name with the previous insect, and because we do not have a separate chapter for gall insects. The blue gum chalcid distorts and stunts growth of mostly nursery eucalypts (Figure 4-16), but also older trees, with, on average, 2.1 mm long, bump-shaped galls on the leaf midribs, petioles and stems of new growth (Mendel et al. 2004). Hosts often develop an umbrella-shaped canopy. This Australian native has become a serious pest in the Middle East, the Mediterranean and in Africa. It was first spotted in a nursery in Kisumu, Kenya in 2003, probably having entered from Uganda. Three varieties of eucalypts are so far affected in Kenya and ten species of eucalypts in Israel. The insect is 1.1-1.4 mm long and black, with short antennae. It is a strong long distance flier. It reproduces parthenogenetically and lays about 80-100 eggs per female. Mean development time is 132 days (Mendel et al. 2004). As Kenya has some 50,000 ha in eucalypts, resistance studies are presently underway. In Israel, the planting of *E. camaldulensis,* which had been previously considered virtually pest-free there, has been halted due to this new insect.

Figure 4-16. Galls caused by the blue gum chalcid wasp *Leptocybe invasa* (Eulophidae) on *Eucalyptus camaldulensis.* (From Mendel et al. 2004; reproduced by permission of Blackwell Publishing Ltd.).

3.4. Suborder Prosorrhyncha (=Heteroptera)

The true bugs include some 37,000 plant feeders as well as predators of other invertebrates (Schaefer and Panizzi 2000). Most are fairly large and drab, but some are colorful. The front wings of adults (hemelytra) are unique, in that they are thickened in the basal portion and membranous towards the tip. Many show a pronounced triangular sclerite (meso-scutellum) on the back and scent glands are common on nymphs as well as adults. The beak arises from the anterior part of the head. They prefer nitrogen-rich flowers, ovules, ovaries, ripening and ripened seed of plants, and succulent shoots, feeding on these tissues intercellularly (Schaefer and Panizzi 2000). There are generally five instars.

While this group includes numerous agricultural pests, there are relatively few families and species of interest to East African forestry.

3.4.1. Coreidae: Big-legged Bugs, Leaf-footed Bugs

These mostly mid-to big-sized bugs often feed on legumes, but also other trees (Mitchell 2000). They cause two types of damage. The tip wilters feed in or near vascular tissues of succulent shoots, making them wither. The pod suckers destroy fruits and seeds, as discussed in chapter 7. Some are seasonal pod suckers but may switch to twig wilting when fruits become unavailable.

The adult males often have flared hind tibiae or flattened and spiked hind femora. The membranes of the front wings have numerous, more or less parallel veins. Adults and nymphs are equipped with scent glands. The nymphs are often gregarious.

Anoplocnemis curvipes (F.): *Twig Wilters*. This common and regionally serious pest of a great variety of agricultural crops, shrubs and trees, especially legumes, occurs throughout sub-Saharan Africa. Damage results from the bugs attacking the most succulent portion of stems, buds, leaves, fruits and shoots of healthy plants. If caught in the act, the insect will be sitting on the shoot head down, about 2-10 cm from the tip, drawing sap with its beak inserted in the host tissues (Figure 4-17). Organs attacked wither and die back. Shoots up to 7mm diameter are attacked (Haines 1934). Damage tends to be most serious in nurseries and especially

Figure 4-17. Female twig wilter, *Anoplocnemis curvipes* (Coreidae), sucking sap from expanding shoot of *Albizia lebbeck.* Note scent gland in light area between mid- and hindlegs.

in cultivated legume crops, which have occasionally experienced complete seed failures.

Trees attacked in various parts of Africa include mostly legume species such as *Acacia, Albizia, Cassia, Delonix, Erythrina, Indigofera* and *Samanea saman*, but baobab, *Citrus*, mango, *Ficus*, guava, *Hevea brasiliensis, Combretum, Cussonia, Grevillea, Jacaranda, Kigelia, Podocarpus, Prunus, Spathodea, Sterculia, Terminalia* and *Theobroma* have also been documented as hosts (Villiers 1952; Le Pelley 1959; Schmutterer 1969; Hartwig and De Lange 1978; Schaefer and Panizzi 2000). In South Africa alone, where this insect is perhaps most economically significant, over 104 hosts have been listed (Hartwig and De Lange 1978). In that country, and probably elsewhere, the bugs opportunistically move through a succession of different host species, concurrent with new, lush growth.

Twig wilters are large, impressive bugs. Adults are generally 22-26 mm long (Villiers 1952), but have been reported to measure on average 38 mm in Nigeria (Aina 1975). Males are larger than their mates. Specimens are black or grey, except for the last antennal segment which is bright yellow-orange (Schaefer and Panizzi 2000). In black specimens, the rim around stink glands (located laterally on the metathorax) is also bright orange red. Sexual dimorphism of the hind legs is pronounced (Villiers 1952). The femora of males are much enlarged, curved and carry an impressive pre-apical spine (Figure 4-18). Those of females (Figure 4-17) are thin and relatively straight, with smaller spines. On both sexes, the pronotum is armed with two short, postero-lateral spines curved forward.

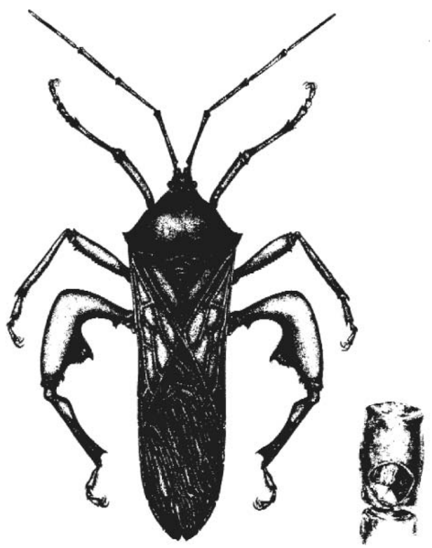


Figure 4-18. Male twig wilter, *Anoplocnemis curvipes* (Coreidae), next to egg. (From Hartwig and DeLange 1978).

According to Aina (1975) and Hartwig and De Lange (1978), who investigated the life cycle of these bugs in Nigeria and South Africa, respectively, females lay batches of 5-36 (avg. 15) eggs several days apart, for an average total of 55, and up to 382. The eggs are brown and measure 1.4-2.4 mm (Figure 4-18). They are barrel-shaped with a conspicuous flap near the anterior pole. Chains of eggs are cemented with the flat side on stems, leaf petioles or on the underside of foliage. Eggs are very often laid on leguminous trees, but nymphs may subsequently feed on neighboring plants, including agricultural crops.

The eggs hatch after an incubation period lasting 6-14 days (avg. 7.5). The first, and sometimes second instar nymphs are gregarious, while the mothers remain in the neighborhood (Aina 1975; Hartwig and De Lange 1978). There are five instars (Hartwig and De Lange 1978). Stink glands of the nymphs are located mid-dorsally on the third and fourth abdominal segments.

From egg to adult emergence takes little over a month in Nigeria, and up to six weeks in South Africa, followed by a pre-oviposition period of about 8-17 days (Aina 1975). The average life span of adults is 22 days, but lab-held specimens live as long as 123 days (Aina 1975). There is a slight preponderance of females. In South Africa there are 2-4 generations per year (Hartwig and De Lange 1978).

Pesticides are not successful against this bug as it only invites the invasion of more bugs from wild hosts (Hartwig and De Lange 1978). Weed control is considered a better strategy. A degree of natural control results from tachinid parasites (*Paraclara magnifica* Bezzi and *Hermya confusa*) attacking almost one in seven bugs in Nigeria and Tanzania. A hymenopterous egg parasite has also been reported.

3.4.2. Miridae: Plant Bugs, Leaf Bugs, Capsids.

This is the most species-rich family in the suborder. Plant bugs are less than 12 mm long, delicate, shy and of variable color. In some species, females are wingless. Winged capsids appear to have a kink in the front wing, the result of a cell called “cuneus”. Most capsids are plant feeders, others are predators and some are both. There are numerous species of serious agricultural pests, but relatively little is known about mirids associated with trees in East Africa.

Helopeltis spp.: *Mosquito Bugs*. Three of the 40 species in this genus from the Old World are polyphagous feeders on trees and many other crops in Tanzania. They resemble *Pachypeltis* bugs and vector pest fungi.

H. anacardii Miller is a sporadically serious pest of cashew in coastal East Africa and Uganda (Hill 1983). Young nymphs feed on the underside of leaves, older ones on young shoots and developing fruits. They distort young leaves and shoots and often cause brooming and dieback. Fruits may abort. Eggs resemble those of *Pachypeltis* and are embedded in soft tips of shoots. There are five instars, the last one yellow and about 4 mm long. Nymphs and adults sport knobbed, hair-like projections on the thorax.

H. bergrothi Reuter reportedly attacked kapok seedlings in a nursery, causing considerable malformations and growth loss (Harris 1938; Morstatt 1942), but also other plants, including fruit trees and eucalypts as listed by Le Pelley (1959).

H. schoutedeni Reuter*: Cotton Helopeltis*. This bug, confined to the wetter savannas and gallery forests of Africa, mainly North of the equator, feeds on succulent tissues of numerous plants, including avocado, *Cinchona*, cacao, cashew, cotton, mango and

Hevea (Evans 1960, Schmutterer 1969, Bohlen 1973, Hill 1983, Villiers 1952). It recently stirred attention, because it was reported to have adapted to young eucalypts in the Congo as had happened previously with related species in Indonesia (Diabangouaya and Gillon 2001).

H. schoutedeni is a narrow, elongated, basically black and red or orange bug (Figure 4-19A) about 7-9 mm long, characterized by very long antennae extending beyond the tip of the abdomen (Villiers 1952; Schmutterer 1969). The nymphs are yellowish-white with red spots and bands (Diabangouaya and Gillon 2001). The eggs are white, elongate and carry two hairs of unequal length at one end. From 30-60, and up to 376 eggs (avg. 30) are inserted into the leaf stalks of hosts, their ends visible (Figure 4-19B). One generation takes on average two months to develop, including 12 days incubation, 28-38 days in the nymphal stage and 33-43 days as adults (Schmutterer 1969; Diabangouaya and Gillon 2001). Like many other tropical Miridae, *Helopeltis* exhibit a more or less continuous cycle of generations throughout the year.

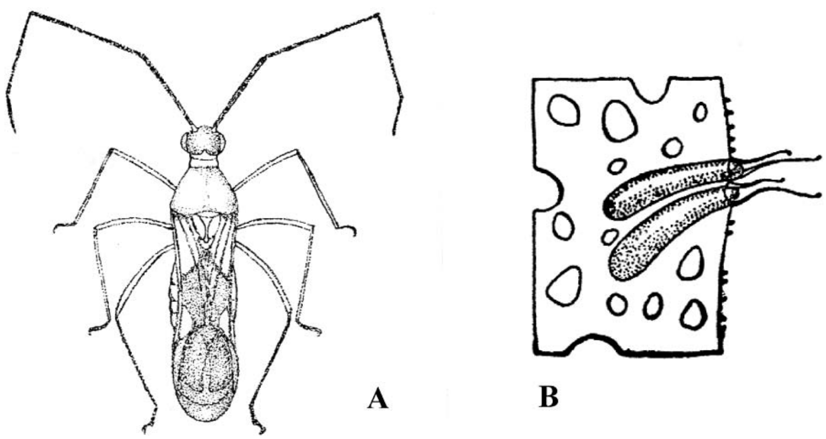


Figure 4-19. The cotton helopeltis *Helopeltis schoutedeni* (Miridae). (A) Adult. (From Schmutterer 1969; reproduced by permission of Elsevier GmbH) and (B) eggs inserted in plant tissue. (From Villiers 1952).

While chemical control is possible, it requires two applications and thus may be prohibitive. As a result, it is likely that in eucalypts clonal differences in susceptibility will be exploited, such as avoidance of the most susceptible hybrids with *E. urophylla* parentage and greater reliance on the most resistant clones with *E. saligna* parentage (Diabangouaya and Gillon 2001). Natural enemies do not seem effective (Speight and Wylie 2001).

Pachypeltis (=Disphinctus) Signoret. This bug was observed at Amani during German colonial days (Vosseler 1906d; Morstatt 1912a). Between December and March it notoriously caused great damage to various crops, including cacao, *Bixa*

orellana, eucalypts and, most seriously, *Cinchona*. It was also observed on castor beans in the Usambaras and on ornamental roses in Zanzibar. The problem usually subsided with the onset of the cold, wet season, when only eggs were found.

The damage resulted from feeding punctures on shoots, fruits and buds, as revealed in 1-2 cm elongated brown-black necrotic lesions often extending to the center of twigs and causing a shoot blight and broomed new growth. Damage was most pronounced on the more succulent shoots, and often leaves were attacked as they just burst from the buds. Such leaves at first showed black spots that developed into brown necroses or shot holes later, and often were distorted.

Nymphs are yellow and red, the antennae and legs red or with red bands. Adult bugs are about 10 mm long, very slender and have black antennae of almost twice the length of the body. Wings are uniformly smoky black or contain three light-colored patches. They extend beyond the abdomen, not revealing much of the general yellow color of the males and red-orange of the females. The legs are either uniformly colored like the body, or occasionally brownish to black in their distal portions. Between the roots of the wings is a 1.5 mm long vertical projection with a small button. Females are somewhat longer and wider than males, and are equipped with a sturdy, saber-like ovipositor, which originates in mid-body. The abdomen terminates with a small cylindrical spike, which is less pronounced in the male.

Females lay 2-25 white eggs, 1.75 mm long, very narrow, rounded posteriorly and truncated at the other end, with an egg cap that is equipped with two beaded threads of uneven lengths. Usually 1-2, rarely 4-5 eggs, are embedded next to each other in tissues at the beginning and end of leaf petioles of *Bixa* or on the underside along the leaf ribs of *Cinchona*, leaving only the two threads visible as the lid seals the hole.

There are five nymphal instars. Like the adults, nymphs hide underneath leaves during the day and can be found on the upper side in the mornings and evenings. They are normally lethargic, but either run away or drop to the ground if disturbed, while the more agile adults quickly fly off for short distances.

Control is considered difficult, as there tend to be no concentrations of the pest, and adults easily escape when approached. Cutting and burning of leaves and shoots containing eggs was recommended. It was also verified, that following manual collection of the bugs from *Cinchona* at Amani one year, the bugs almost vanished the following year. If repeated, this labor-intensive method apparently worked over time. Avoiding the susceptible, small-leaved *Cinchona ledgeriana* and hybrids in favor of the barely affected *C. succirubra*, was also recommended.

Other than these species, *Lygidolon laevigatum* Reuter was reported from black wattle in Kenya and 13 *Lygus* spp. from various other trees, including cypress in Uganda, as listed by Le Pelley (1959).

3.4.3. Pentatomidae: Stink Bugs

Several species of these small to mid-sized bugs are serious agricultural pests attacking buds, bark, shoots and fruits, while some are predators of other insects (Schaefer and Panizzi 2000). In Malawi, several unspecified stinkbugs attack exotic conifers and eucalypts, causing some damage and distortion (Esbjerg 1976). The closely related Scutelleridae are discussed in chapter 7 in conjunction with seed damage.

Stink bugs are of a shape that superficially makes them resemble beetles. Most characteristic is a large triangular area in the middle of the thorax (meso-scutellum) (Figure 4-20). Their name derives from stink glands, which are located on the abdomen in nymphs, and behind the hind legs in adults. Most species are green or brown, while others are colorful. Adult stink bugs often assemble on trees in large numbers at the end of rains or during the dry season, and some are collected for human food as described in chapter 9.

Figure 4-20. A typical stink bug (Pentatomidae). This family includes plant feeders, predators and edible insects.

3.4.4. Tingidae: Lace Bugs

This is a family of very small, less than 5 mm long bugs, with perhaps 2,000 species worldwide (Stonedahl et al. 1992). All are plant feeders, some host-specific on trees. They feed on lower leaf surfaces, attacking the palisade parenchyma. This causes stippling, withering and premature leaf fall. Feces and shed skins are intermixed with bugs of various instars and stages. One South American species, *Teleonemia scrupulosa* Stål, was introduced into East Africa in 1953 for biological control of *Lantana.* Although the bug became established, it did not exert sufficient control on this weedy shrub, and unfortunately became a pest of sesame (Le Pelley 1959; Stonedahl et al. 1992).

Lace bugs have a reticulated network of ridges that divide much of the visible thorax and the fore wings into a series of cells. Their antennae are 4-segmented, the first and second segments short and thick, the third one much longer and slender. The tarsi are 2-segmented and there are no simple eyes. The first thoracic segment and abdomen often have pronounced outgrowths. Females insert their eggs into plant tissues and the five instars are supervised by their mother.

The following species are representative for Tanzanian lace bugs feeding on trees. *Cysteochila endeca* Drake is primarily a pest of tamarind, but also feeds on *Gardenia* and potato in the afrotropical region (Stonedahl et al. 1992). *Compseuta ornatella* (Stål) occurs from Nigeria to the Sudan and South, and in Tanzania is found on *Abutilon* and *Cordia* (Duarte Rodrigues 1979; Stonedahl et al. 1992). The fifth instar of this species is 2.36 mm long, 1.16 mm wide, black and carries long lateral spines to the tip of the abdomen. Another five spines are on the back of head. The first, second and fourth antennal segments are brown, the third is brick-colored. Legs are mostly brown. The adults are 3.25 mm long, black bugs, with yellow elements on the forewings, pronotum and legs (Villiers 1952).

CHAPTER 5

SHOOT, BARK AND WOOD BORERS

1. INTRODUCTION

Forest insects attacking succulent shoots, the bark and wood of stems, branches and roots, or wood products, are often lumped together under the term borers. Many termites rightfully belong to this group, but will be discussed separately in chapter 6. Given the large number of shoot, bark and wood borers, it is not surprising that their appearance, habits and evidence are also diverse. As a result, it may be useful to first discuss why borers live inside trees, which stage(s) may be involved with this activity, the range of host preferences and signs or symptoms of attack.

1.1. Purpose of Lignicolous Habit

Insects bore inside bark, shoots and/or sound wood for two basic reasons, i.e., for food and/or to make a home. Food is obtained either by feeding directly on bark (phloeophagy), or wood (xylophagy), or indirectly by using wood as a medium for the culture of specific food fungi (xylo-mycetophagy) which contain concentrations of scarce nutrients (N, P, K). There are also rotten wood eaters that require wood to be predigested by fungi. Many wood borers eating sound wood do not digest cellulose directly, but instead employ gut symbionts (bacteria, fungi or protozoans) that supply wood- digesting enzymes. All of these borers enjoy the dual benefit of living in, while eating parts of their abode. Others only carve a home into wood while relying on external sources of food.

1.2. Stages Involved in Tunneling

The term boring implies that the immature and/or the adult stage tunnels inside a tree for at least part of the life cycle. Often adult females initiate borer attacks on trees or wood, usually attaching their eggs to the surface of exposed wood, inserting them into cavities of exposed wood, or chiseling egg niches into the bark. In a group of specialists called “girdlers”, the female selects healthy host branches or small stems and cuts a complete and precise circle through the bark into the wood before laying

eggs, mostly distal to the girdle. In all these cases, the immature stage is called "timberworm" (Coleoptera) or "carpenterworm" (Lepidoptera) and accounts for the internal tunneling. Adults of these insects may be briefly found in wood when hatching in a pupal chamber or while digging an exit tunnel to the exterior. In certain other groups of wood borers, i.e., the pin-hole borers and carpenter bees, the tunneling is exclusively done by the adults, while the larvae inhabit the tunnels built by their parent(s). In the case of bark beetles and certain shot-hole borers, both adults and larvae are borers.

1.3. Host Preference

Host-specificity (monophagy) in East African wood borers is rare. For instance, *Phloeosinus bicolor* (Brulle) appear to be restricted to hosts in the family Cupressaceae. Many other borers attack a number of hosts (oligophagy), while still others are highly non-discriminating opportunists on many hosts (polyphagy). The latter group frequently includes species that attack both hardwoods and conifers, and sometimes palms or non-woody hosts. Most beetles have broad food preferences.

1.4. Host Part Preference

While some borers specialize on parts of tree stems, such as the succulent shoots, the phloem, sap- or heartwood, others are less discriminating. For instance, many subcortical feeders progressively move from the phloem and cambium into the outer, non-lignified sapwood, and some advanced instars may penetrate even deeper into the older sap- and heartwood.

Nutritionally, developing shoots and the subcortical zone of trees, including inner bark (phloem), cambium and the immature outer sapwood (xylem) are generally superior to the older parts of the sap- and heartwood. The latter often contains substances that discourage attack, except by specialists.

In addition to host-part specificity, there is also size-specificity. While many borers limit themselves to seedlings, saplings or small twigs, branches or stems, others prefer pole-sized material, and still others mature stems. Borers that depend on stable moisture conditions, such as the fungus-cultivating pin-hole borers, tend to select larger dimensions.

1.5. Condition of Host or Wood

Borers also differ in their preference for or ability to attack hosts or wood under certain conditions. The four categories of attack suggested for Cerambycidae (Hanks 1999) generally apply to other borers as well. Some borers attack only healthy hosts (HH) and normally do not continue to develop after their host tree has died or been felled. Other borers are only successful with dead hosts or wood in storage or service

(DH). In between are borers which attack weakened hosts (WH) and stressed hosts (SH). The border between these two categories is hard to delineate, but typically weakened hosts may recover, when the condition accounting for their weakness, such as drought or site conditions, are reversed or improved. On the other hand, stressed hosts, such as those severely impacted by drought, fire or high age may be in irreversible decline. This latter category also includes recently fallen branches or logs and felled trees that still contain live tissues. For dead wood in the forest, wood in transit, wood in storage and wood in use, the amount of starch and moisture usually explains differences in susceptibility to various groups of insects.

If climate changes will cause shifts from subtropical dry and subtropical moist forests to tropical very dry and tropical dry forests, as predicted by one climate model scenario for Tanzania (Mwandosya et al. 1998), the role of WH and SH borers and some other insects is likely to be enhanced.

In trying to apply the four categories of host condition, it is important to recognize that essentially healthy hosts normally have weakened, stressed or dead parts, and borers exploit those conditions. This is particularly true for shaded branches preparing to shed and various localized injuries that trees usually are capable of isolating from healthy tissues in an orderly process called compartmentalization.

Besides the four attack categories identified by Hanks, Eidmann (1943) differentiated four insect-related successional stages (I-IV) in the breakdown of wood, with one and the same host potentially exhibiting several of these simultaneously in different parts. Stages I (bark and ambrosia beetles), and II (longhorn beetles, metallic wood borers, weevils and termites) involve relatively few specialized pests, while stages III-IV represent numerous generalist decomposers. Each stage is also associated with a characteristic set of predators, parasites and other associates, such as space parasites, many forming more or less specific alliances with the borer guild. Dead bark and wood are indeed very much alive, including numerous biota and niches remindful of mini-Serengetis.

1.6. Evidence of Attack

Borer activity results in both external and internal signs and symptoms. The most conspicuous external evidence in living trees are characteristic holes (egg niches as well as entrance, aeration and exit holes) often in conjunction with the flow of tree sap (flux, resin or gums) and extrusions of powdery, granular or fine or coarse fibrous particles (frass) consisting of bark, wood and/or feces. Trees fighting an attack may also develop bark welts. In a number of beetle borers, the adults reach sexual maturity only following a period of feeding, which often involves the chewing of living bark on twigs, branches or stems. This may result in flagging or small, canker-like bark deformities. Flagging is also associated with bark girdles, i.e., complete circles of severed bark around a branch, resulting from the activity of certain specialists.

Internal evidence includes tunnels (=galleries), frass, and pupal chambers or chip cocoons. Frass can be powdery, granular, fine fibrous or coarse fibrous. Tunnels of uniform width result from adult borers and are usually clear of frass, while galleries of increasing size are made by larvae and may, or may not, contain frass. Kirkpatrick (1944) referred to these types of borer damage as “pin-holes” and “worm-holes”, respectively. Typically only one generation of these borers develops in a susceptible host. A third category called “powderposting”, applies to intense tunneling (honeycombing) of seasoned wood by successive generations of borers that eventually turn it into a fine powder. Secondary signs include dark stains surrounding the galleries or pure fungal cultures growing in them.

When assessing borer damage, it is also useful to consider the host species; host age; host part (shoot, twig, branch, trunk, root); host condition; the depth of attack; host tissue concerned (bark, sapwood, heartwood) and the nature of the wood (dry, moist, firm, rotten).

1.7. Impact of Borers

At the tree level, borer activity interferes with growth, by impeding the downward and upward movement of liquids. Their tunnels and the action of associated fungi compromise the flexibility, storage capacity and structural strength of wood in general. In human terms, borers cripple and cause circulatory disease, muscular decline and osteoporosis.

At the ecosystem level, all bark and woodborers are important contributors to nutrient and carbon cycling and thus ecosystem health.

At the smaller scale of human enterprise, borers cause significant economic concern for both field forestry and wood utilization. During parts of the British colonial era, entomologists were preoccupied with borers, which resulted in a relatively large store of knowledge and documentation. This focus developed when resistant timbers such as mvule and juniper were no longer sufficiently available to meet growing demand, and when the less resistant substitute timbers suffered noticeable losses from borers (Gardner 1957b).

The concern over borer impact generally depends on host and insects involved. By attacking living, healthy trees, girdlers, shoot and twig borers primarily deform hosts and cause some growth loss. Some bark beetles vector fungi that initiate and/or accelerate a tree’s decline or death, while borers in general, structurally weaken hosts, reduce growth and set the stage for secondary invaders. Those borers attacking weakened hosts typically complicate their recovery, and thus may edge them towards decline and potential death. Wood borers attacking stressed hosts accelerate their death and may affect the visual or technical quality of potential wood products. Newly dead salvageable trees, felled timber, lumber and wood in use may also be compromised by stains or tunnels, or may be completely destroyed. In a few cases,

the effects of borers actually meet the special needs of craftsmen who see “character”, where others see flaws (Plate 31). Such wood may be more highly valued than sound wood in the same way that amber with insect inclusions commands a higher price than pure amber.

1.8. Orders of Shoot, Bark and Wood Borers

This chapter features borers representing three orders: Coleoptera, Hymenoptera and Lepidoptera. The Isoptera will be discussed in chapter 6. Given their huge numbers, the appearance and life histories of borers are extremely diverse. They include representatives ranging from tiny to huge, from mono- to polyphagous and from solitary to social. Some have relatively short developmental periods, while others have some of the longest known among insects.

This diversity makes it difficult to organize borers into logical groups. Various authors have chosen to categorize borers according to size, the condition of the host, the part of host attacked, the nature of tunnels or frass, or other such practical criteria. Unfortunately, these categories create as many problems as they solve, and frequently lead to a proliferation of trivial characteristics. For instance, certain insect families, composed mostly of big representatives, also contain very small species. Different species in the same families may attack healthy, weakened, stressed and/or dead trees and wood, most of these categories with uncertain transitions. Families that mainly construct larval galleries of increasing size may also include species with adult tunnels of uniform width. Different species in the same or other families may have fine, granular or fibrous frass. Several large families include shoot, bark, twig, trunk, root, sapwood and heartwood borers as well as girdlers, creating tunnels of different shape and size. As a result of these considerations, the borers will be arranged simply based on taxonomic classification, i.e. orders, families and subfamilies. An overview of other criteria is presented for coleopterous families in Table 5-1. Management questions for various borers are discussed on an individual or family basis.

2. COLEOPTEROUS BORERS

2.1. Bostri(y)chidae: Shot-hole, Auger, Branch or Twig Borers, False Powderpost Beetles

This family of about 650 species of beetles with many representatives in Africa (Lesne 1924), consists of at least 19 genera and 42 species in East Africa, and a minimum of 12 genera and 22 species inTanzania (Gardner 1957a; Le Pelley 1959). At one time, the family Bostrichidae also included the now independent Scolytidae.

Bostrichids are economically important, often highly polyphagous borers in the dry, starchy sapwood of partly or fully seasoned lumber, as well as in twigs and branches of living, dead or felled hardwoods and occasionally also in softwoods or bamboo (Lesne 1924; Gardner 1957a,b; Jones et al. 1966; Schabel and Madoffe 2001). Common predators of bostrichid grubs include larvae and adults of checkered

Table 5-1. Major families of shoot-, bark- and wood-boring Coleoptera in East Africa.

Family	*Borer stage*	*Food habits*	*Successional stage (I – IV)*	*Host condition*	*Antennae of adults*	*Size of adult*
Bostrichidae	I (A)	XP	II	(WH) DH	3-segm. club	S-M
Brentidae	I	XP	II	SH, DH	beaded	M
Buprestidae	I	PP-XP (R)	II	WH, SH	saw-like	(S) M (L)
Cerambycidae	I	PP-XP (R, SB)	(I) II (III)	WH, SH, DH	whip-like (saw-like)	(S) M (L)
Curculionidae	I	XM	III	(WH) DH	elbowed	(S) M
Lyctidae	I	XP	II	DH	2-segm. club	S
Lymexilonidae	I	XM?	II	SH, DH	beaded	M
Platypodidae	(I) A	XM	I	(WH) SH	1-segm. club	S
Scarabaeidae	A	T	I	HH	bladed club	M-L
Scolytidae	I A	XM, PP, R, SB	I	(HH) SH	1-segm. club	S

A = adult; DH = dead host; HH = healthy host; I = immature; L = large; M = medium; PP = phloeophagous; XM = xylo-mycetophagous
XP = xylophagous; R = root borer; S = small; SB = seed borer; SH = stressed host; T = terminal shoot borer; WH = weakened host

beetles (Cleridae). While most bostrichids are larval wood borers, certain species are more important as adult borers.

2.1.1. Description and Life History

Bostrichids are cylindrical beetles with parallel-sided wings. They are in the 2-23 mm range, dark brown to blackish and often in part reddish. The small head is concealed from above by the hood-shaped prothorax. The antennae are short and carry a three-jointed club. Grubs (Figure 5-1) are white, curved and have a slightly enlarged thoracic region with three pairs of short legs (Gardner 1933).

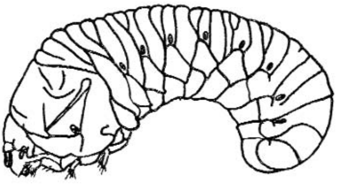


Figure 5-1. : Lateral view of larva of *Heterobostrychus brunneus* (Bostrichidae). (From Gardner 1957b).

In most species, there are 1-3 generations per year (Gardner 1957b). Females bore into the wood to lay eggs, but eggs can also be inserted into old emergence holes or cracks. Some species show a crude form of social life with males helping the females bore the egg tunnel and often remaining for a while to guard the eggs (Skaife 1979). While the tunnels built by the adults are fairly uniform and clean, the larval tunnels are packed with powdery frass and increase with size as the insect grows. Pupation takes place near the wood surface, to allow the beetles to escape with minimum effort through circular exit holes.

2.1.2. Apate spp.: *Black Borers*

This genus is one of the most notorious and troublesome forest pests in Africa, as well as in South America (Schabel et al. 1999). While most other species in this family and the larvae of *Apate* feed in the sapwood of dead branches or in seasoned lumber, *Apate* adults also feed inside living trees and shrubs of numerous indigenous and exotic hard- and softwood species (Schabel and Madoffe 2001). Attacks by these non-selective feeders are typically sporadic, but can occasionally be severe, especially in living shrubs (e.g. coffee) and trees in young plantations and taungya farms. Maturation feeding by the beetles sometimes kills hosts, but more often they may break in strong winds. In recent years, *Grevillea robusta* came under attack from *Apate* sp. in the Kenya Highlands (Rao et al. 2000).

The approximately 20 mm long beetles bore tunnels about 6 mm wide. Evidence may not be obvious externally, but internally the wood is often severely riddled, gummed and stained. Adult black borers usually prefer trees and seedlings stressed by dry season conditions, i.e., drought and fire (Gardner 1957a).

At least eight species of *Apate* occur in East Africa, of which three (*A. indistincta* Murr., *A. monacha* F. and *A. terebrans* Pall.) have been reported from Tanzania (Gardner 1957a; Le Pelley 1959).

A. indistincta attacked healthy black wattle but were repelled by copious gum exudations (Gardner 1957a). Presumably the same happened in an attack on supposedly

healthy *Eucalyptus camaldulensis* (Gichora and Owuor 1990). Beetles were also found in living *Maba buxifolia* and in a teak plantation of poor quality. Larvae were reared from several dry hardwoods. In Kenya the life cycle takes twelve months starting in April. One female contained 146 eggs (Gardner 1957a).

A. monacha is widespread in the rest of Africa as well as in the Mediterranean and, as an introduced species, in South America (Lesne 1924). This borer is extremely polyphagous. Hosts include coffee and palms, *Acacia, Casuarina, Cupressus, Erythrina, Grevillea* and *Schinus,* just to name the most common. There may be several beetles per feeding gallery (Mallamaire 1933). Mature larvae are 10-20 mm long, white to pinkish and are found in dead branches. Adults are agile, strong, nocturnal fliers. The beetles are black, have a massive square thorax, and a rectangular body with parallel sides. The thorax and abdomen are granular and shiny, the antennae brown at the base and yellow-red at the tip.

A. terebrans (Figure 5-2) resembles the previous two species and behaves similarly. It has been reported on a number of hosts, including *Delonix regia* and various crop trees in Tanzania (Gardner 1957a; Le Pelley 1959). This beetle, which can kill young trees, occurs through most of sub-Saharan Africa, Madagascar and as an exotic in Central- and South America.

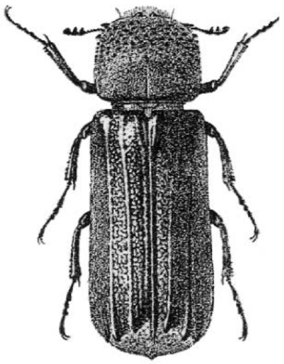


Figure 5-2. Female of the black borer *Apate terebrans* (Bostrichidae). (From Lesne 1924).

Maintaining tree health appears to be the best strategy for dealing with *Apate* spp. In high value trees, it may also be feasible to winkle the beetles in their tunnels, i.e. to spear them with wire (Hill 1983), or to insert insecticide-soaked cotton into their tunnels.

2.1.3. Prostephanus truncatus (Horn)*: Larger Grain Borer*

Since its discovery in Tabora in 1981 (Hodges et al. 1983) and in Togo in 1984, this beetle, originally an endemic and minor pest in Meso-America, has spread to other parts of Africa, where it became a major pest of stored maize and cassava. After 18 years, it has been confirmed in at least eight countries in West Africa, and from Kenya to South Africa. Although primarily an agricultural and storage pest, trees are an important reservoir. The beetles are believed to reproduce in dead branches and roots, as well as seeds of a variety of woody hosts in forests and savannas (Nang'ayo et al. 2002; Hill et al. 2003). In Mexico, Benin and Kenya, colonies of the beetle are often found in association with twig-girdling cerambycids. Under laboratory conditions, the beetle reproduced in 27 out of 84 native and agroforestry trees and shrubs tested in Kenya. Breeding success varies widely between host species, with survival being highest in stem sapwood (Nang'ayo et al. 2002). In West Africa it reproduced in over 20 species of trees, including teak (Nansen et al. 2004).

The black beetles are about four millimeter long and the slightly ridged tip of the elytra is square (Rees 2004). After a 5-10 day pre-oviposition period, the female constructs tunnels and side chambers in the food source and lays 7-8 eggs per chamber, averaging a total of 430 eggs. There are three larval instars. Development from egg to adult takes 26 days under optimum conditions, and adults live for at least six months (Borgemeister et al. 2003). In woodlands of Kenya there is a single strong peak for the beetles from November to January (Hill et al. 2003).

For control of this pest, an integrated strategy involving chemical, biorational and biological methods has been pursued. In storage, pyrethroids and pheromones have been used, and the predatory beetle *Teretrius nigrescens* (Lewis) (Col: Histeridae) was released in West and East Africa, including Tanzania (Hill et al. 2003). Although quite an effective predator, the impact of this histerid is, unfortunately, not consistent over large areas for long time spans. It is believed to be more effective on host populations in the forest than under storage conditions (Borgemeister et al. 2003). The pheromone, produced by males to attract both sexes, is a highly effective monitoring tool for dispersing beetles.

2.1.4. Less Important Bostrichids

Bostrychoplites cornutus (Ol.). The horned shot-hole borer is common and widespread in the Afrotropics. This 6.5-17 mm long, dark brown beetle is distinctive, as the front of the prothorax carries two stout horns (Figure 5-3). The larvae attack furniture, poles and logs of a variety of trees, including *Acacia, Albizia, Chlorophora, Commiphora, Podocarpus* and *Eucalyptus.* The beetle is frequently seen at lights.

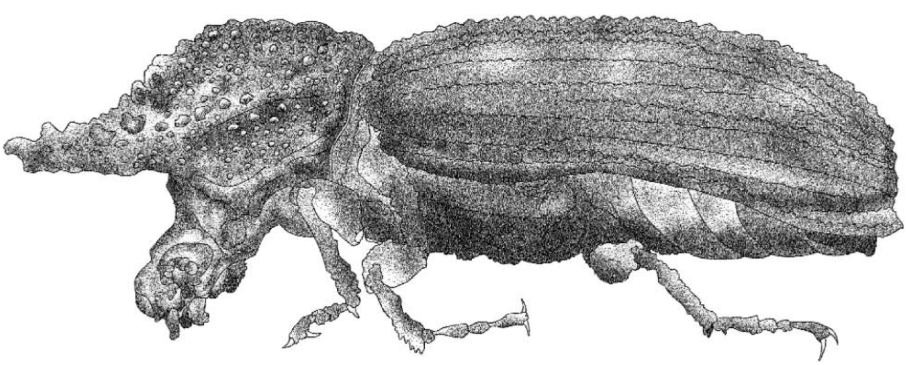


Figure 5-3. Lateral view of the horned shot-hole borer *Bostrichoplites cornutus* (Bostrichidae). (P. Schroud).

Bostrychopsis villosula Les. is one of the more common shot-hole borers, riddling stored and sawed timber as well as structural wood in at least ten hardwood and one conifer genus (Gardner 1957a, b).

Dinoderus minutus F. The bamboo borer originated in the Far East but is now widely distributed throughout the tropics, including many parts of Africa and Tanzania (Lesne 1924; Beeson and Bahtia 1937; Peake 1949; Gardner 1957a). It is a serious pest of bamboo in cane chairs and wickerwork, but attacks hardwoods as well (Austarå 1969; Gardner 1957a; Skaife 1979). Adults (Figure 5-4) are from 2-3 mm long and dark brown. The larva is typical for bostrichids. There are 3-4 generations per year.

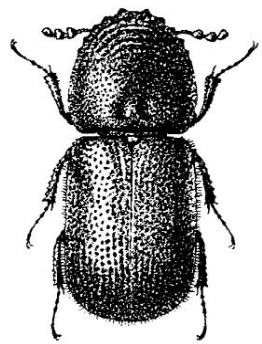


Figure 5-4. The bamboo borer *Dinoderus minutus* (Bostrichidae). (From Lesne 1924).

Heterobostrychus brunneus Murr. larvae also cause great damage to sawn timber in storage or use throughout sub-Saharan Africa, including at least nine hardwoods as well as some softwoods (Gardner 1957b). Larvae are typical (Figure 5-1). The beetle resembles *B. cornutus,* but is only 7-10 mm long, browner and carries less pronounced thoracic horns. Like *B. cornutus,* it is common around sawmills (Esbjerg 1976).

Sinoxylon transvaalense Les., the acacia shot-hole borer, is common throughout sub-Saharan Africa, where it infests woody legumes, but also *Combretum* and *Terminalia* (Gardner 1957a). It is about 6 mm long, black and has a pair of spines near the tip of the front wings (Skaife 1979).

Xylion adustum Fhs., widely distributed from Ethiopia to South Africa, attacks the sapwood of many species, especially poles and planks (Gardner 1957b).

2.2. Brent(h)idae: Primitive Weevils, Straight-snouted Weevils; Timberworms

These beetles (Figure 5-5) mostly inhabit warm climate forests. There are at least 38 species in Tanzania, many being widely distributed in Africa (Muizon 1960; Damoiseau 1967). Included are mycetophagous and xylophagous species, as well as space parasites and some, at least partially, predaceous species. Most are simple wood borers whose larvae tunnel in many species of hardwoods (Gardner 1957a; Le Pelley 1959). The condition of the wood seems to be more important than the species (Löyttyniemi and Löyttyniemi 1987b). The overall importance of brentids in East Africa is uncertain and no one species is prominent (Gardner 1957a).

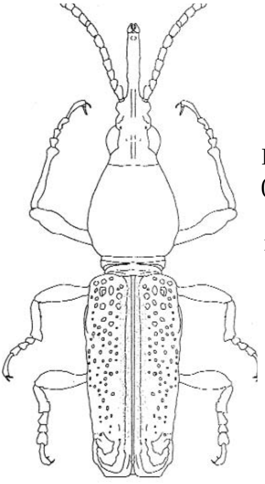


Figure 5-5. Most brentids (Brentidae) in East Africa resemble this species from the Uluguru Mts. (P. Schroud)

The adults are 4-40 mm long, parallel-sided, slender, brown or black beetles. The head is sometimes very narrow and elongated into a pronounced snout. The antennae are beaded. Eggs are laid into holes drilled into bark and the larvae bore deep into the sapwood. They are elongated, cylindrical grubs with a slightly enlarged thoracic region and sometimes tiny legs. Their round tunnels resemble those of ambrosia beetles but increase in size as the larva grows. In many species the femora are enlarged and the striation of the front wings is pronounced. In Zambia they fly throughout the year, but mostly during the rainy season (Löyttyniemi and Löyttyniemi 1987b). The beetles are attracted to light.

2.3. Buprestidae: Jewel Beetles, Metallic Wood Borers; Flat-headed Borers, Horseshoenail Grubs or Hammer Grubs

This large family consists of over 15,000, mostly tropical beetles. Only few develop in living trees while the majority attack weakened, stressed and recently felled hosts (Gardner 1957a). They tunnel mostly in the subcortical zone of trunks, branches, twigs and roots although some of the larger larvae also dig deeply into the stem and into the heartwood. Some buprestids in the temperate zones are fairly or highly host-specific while a number of tropical species are polyphagous. For instance, in many parts of the Afrotropics, *Chrysobothris dorsata* F. attacks dead trees and logs of acacias, *Acrocarpus fraxinifolius*, *Grevillea robusta* and *Teclea viridis*, among others. Some of the smaller species are leaf or stem miners, and the larvae of some of the largest (*Sternocera* spp.) are external root feeders. Many adults are important pollinators.

2.3.1. Description and Life History

The beetles are 2-50 mm long and often brilliantly metallic which makes them choice specimens for collectors as discussed in chapter 9. Most striking are those species with a coppery, blue, green, and orange sheen. Others are more somber black or brown, but still polished and attractive because of white lines and spots or interestingly sculpted surfaces. Their elongate, sleek body and hard exterior resembles an armored speedboat (Figure 5-6). The head is often pulled back into the prothorax and carries fairly short, thread- or saw-like antennae.

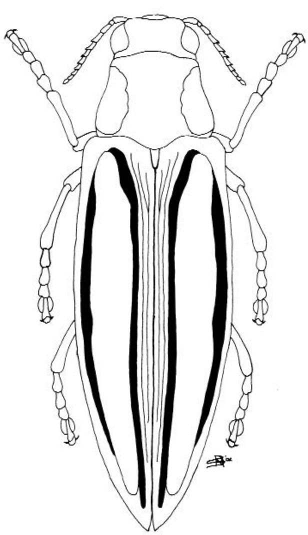


Figure 5-6. Chrysochroa lepida (Buprestidae), a typical representative of the metallic wood borers (Buprestidae). Early March, Morogoro. (P. Schroud).

The larvae (Figure 5-7) are legless, slender grubs. The prothorax is usually flattened and broad, making it resemble a large, pancake-like head. This appearance accounts for their names flat-headed borers, horseshoenail grubs or hammer grubs.

Figure 5-7. Flat-headed wood borer or horseshoenail grub (*Chrysobotris* sp.) a typical representative of metallic wood borers (Buprestidae). (From Scholtz and Holm 1985; reproduced by permission of the University of Pretoria).

Little is known about the biology of East African buprestids. In Zambia, they have been caught throughout the year, but some species were limited to or concentrated in the dry hot season, when trees are stressed, as well as during the early rainy seasons (Löyttyniemi and Löyttyniemi 1987a). Most have one generation a year, while others such as *Agrilus aedil* Obenb. and *C. dorsata* may have several overlapping generations. In some species the life cycles are said to take up to 35 years, longer than for any other insect (Picker et al. 2002). The beetles are most active during the heat of day at which time they visit flowers, feed on leaves or scurry on the bark hunting for mates or cracks in the bark to lay eggs. Because of their large eyes and excellent vision they are highly alert and fly off quickly when approached. The grubs gnaw flat, wide galleries with often alternating darker and lighter bands packed with fairly fine frass. The shallow pupal cells are located in the sapwood.

2.3.2. Representative Species of Buprestids

Some 25 species of East African buprestids together with known hosts are listed by Gardner (1957a) and Le Pelley (1959), but there are many more in Tanzania. Since most are restricted to the bark and outer sapwood of weakened and stressed trees or fresh logs, they are generally not important pests. In Kenya only the following two were recorded as tunneling in living trees (Gardner1957a, b).

Steraspis speciosa fastuosa Gerst. This borer was observed gumming eggs onto the bark of *Elaeodendron* and *Cassia fistula* and the larvae were boring directly into the wood causing much exudation of gums in the former. Large and extensive tunnels through the middle of the stem with frass ejection holes at intervals caused sufficient damage to kill young trees.

Agrilus spp. This cosmopolitan genus of over 1,000 species is one of the more important genera of buprestids in many parts of the temperate zones. In their natural range, they normally attack and kill only severely weakened or stressed indigenous hosts, but when confronting exotic trees, some have become killers of healthy trees.

In East Africa, larvae of at least ten species of *Agrilus* are very common under the bark of some logs, especially *Albizia*, where they tunnel in characteristic zigzag fashion giving the genus the common name varicose or zigzag borers. Among several species, *Agrilus* near *grandis* C.& G. was singled out as it attacked 40% of trees in

a small plantation of *Acacia mollissima* in Kenya (Gardner 1957a). Despite copious gum flow on stems and branches, the trees did, however, survive. Following a serious drought in the Sudan, several buprestids, including *Agrilus* spp., reduced gum Arabic production in acacias (Jamal 1994). Living trees fighting the larvae often revealed raised welts in the bark.

Larvae of *Agrilus* are easily recognized by a pair of short, dark spikes at the tip of the abdomen. The beetles are mostly in the 10 mm range and very narrowly built in the shape of a flat, reverse bullet (Figure 5-8). They escape from telltale exit holes shaped like a D.

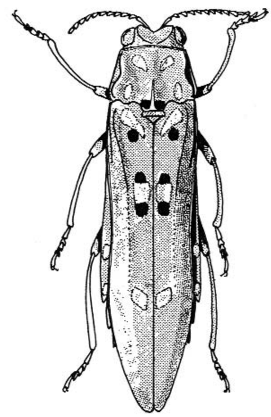


Figure 5-8. Agrilus sexguttatus (Buprestidae). (From Scholtz and Holm 1985; reproduced by permission of the University of Pretoria).

To prevent the buildup of buprestids around sawmills, fresh logs should be decorticated as soon as possible to prevent the accumulation of wooden slabs with intact bark.

2.4. Cerambycidae: Longhorn Beetles; Round-headed Borers

This is a very large family with more than 35,000 plant-feeding species in about 4,000 genera (Hanks 1999). Numerous representatives are associated with trees or wood in East Africa as reflected in Gardner's (1957a) 11-page list of species. Extensive descriptions for many African species, including some 60 species from Tanzania, are available in Duffy (1957, 1980).

2.4.1. Host Relationships

The larvae of most cerambycids bore in shoots, twigs, stems and roots of woody plants. A few small species develop in seeds and others attack herbaceous plants. Hanks (1999) differentiated four categories of host selection by cerambycids, including healthy hosts (HH species), weakened hosts with recovery potential (WH species), severely stressed or moribund trees, including recently felled trees (SH species) and dead or decaying trees, including seasoned, structural wood (DH species). While these categories can be readily applied in some cases, records do not necessarily allow consistent and reliable interpretation of host relationships in others.

There are also distinct differences with respect to which part of wood cerambycid larvae develop in (Hanks 1999). Many HH and WH species feed relatively briefly in the subcortical area (inner bark, cambium and young sapwood) before spending the remainder of the developmental period in the sap- and/or heartwood. SH species feed almost exclusively in the subcortical zone. They often scour the outer sapwood but only invade it for pupation or if they should run out of subcortical tissues before reaching maturity. Although many DH species prefer the subcortical zone, others are

also found in the sapwood, or after depletion of this zone, in the heartwood. Certain HH species, including shoot borers and girdlers, are specialists that select the healthiest and youngest shoots or saplings for oviposition. The shoot borers are attracted to actively growing, succulent shoots or terminals, while the girdlers attack lignified, healthy branches. In the girdlers, the female beetle chews a complete circle through the outer layers of the wood from the outside before laying eggs on the distal part of the branch, effectively converting a healthy host branch into an SH host. The severed branch or trunk tends to eventually break off. In rare cases, the larvae of certain species build a circling tunnel under the bark of branches from the inside, which also leads to breakage. These beetles are called "pruners".

While some cerambycids are fairly specific in host and host part selection, the frighteningly long catalogs of hosts by Gardner (1957a) for East Africa and Duffy (1957, 1980) for Africa, attest to the polyphagous nature of many.

2.4.2. Description and Life History

Cerambycids include very small seed borers, but the majority tends to be middle-sized to large. The largest beetle on Earth, a South American species, is in fact a member of this family. Most species, especially the males, have long, whip-like antennae accounting for their name, longhorn beetles. The compound eyes often wrap horseshoe-like around the base of the antennae. There appear to be four tarsal segments, the third being bi-lobed, although a close inspection will reveal a very small, hidden, fifth segment between the last two segments. Depending on species, the grubs have, or do not have, short, thoracic legs. Their common name, "round-headed wood borers", is not generally justified by morphological evidence and may be based on the round exit holes.

Oviposition usually takes place either in cavities chewed into the bark by the female or into existing cracks in host surfaces. Depending on the nutritional status and moisture content of the food, the grubs take from a few months to many years to develop and their size, within one species, may vary considerably. Those developing in the subcortical zone generally have shorter life cycles while those in seasoned, structural wood may take more than a decade. Depending on species, frass either accumulates in the galleries or is periodically ejected. Pupation usually takes place inside the host in a pupal chamber just under the bark. Root feeders may pupate in the soil. During their short adult life, which usually coincides with the onset of the warm season (Löyttyniemi and Löyttyniemi 1983), various beetles feed on either flowers, soft foliage and shoots, running sap, bark or fruit. Some do not feed at all. Certain, mostly drab-colored species are only active at night while others are diurnal and may be colorful. When handled, adult beetles may emit a squeaking sound produced by rubbing the hind margin of the pronotum against the anterior edge of the elytra. In the Zambian miombo, July was the only month when the flight of cerambycids ceased.

There are at least nine subfamilies of cerambycids, but only three are more or less economically significant in East Africa. Most of the more serious timber pests belong to the Cerambycinae or Lamiinae, two subfamilies which are most diverse in the tropics. The Prioninae are generally more impressive in size but less serious as pests. These three subfamilies are occasionally treated as families in their own right.

Given their numbers and the economic significance of at least some Cerambycidae, a key (Table 5-2) to the five subfamilies likely to be encountered in Tanzania is provided (after Booth et al. 1990).

Table 5-2. Key to major subfamilies of Cerambycidae in Tanzania.

1	Antennae inserted fairly close to the bases of the mandibles	2
	Antennae not inserted fairly close to the bases of mandibles	3
2	Lateral borders of pronotum distinct, at least in basal half, often dentate or serrate. Procoxae strongly transverse	Prioninae
	Lateral borders of pronotum very rarely distinct. Procoxae rounded.	Aseminae
3	Head generally elongate and strongly constricted behind eyes. Conical, projecting procoxae	Lepturinae
	Head generally not elongate and not strongly constricted behind eyes. Proxoxae not conical and projecting	4
4	Protibiae not obliquely grooved before apex. Head more or less obliquely inclinedanteriorly. Apical segment of palps truncated. Hind legs usually long.	Cerambycinae
	Protibiae obliquely grooved internally before apex. Head more or less vertical in front or with mouthparts directed somewhat backwards. Apical segment of palps tapering towards tip. Hind legs usually relatively short.	Lamiinae

2.4.3. Cerambycinae

Beetles in this very large subfamily are of moderate to large size. They differ from the Lamiinae by having anterior tibiae not obliquely grooved before the apex, by having the head more or less obliquely inclined anteriorly, by having blunt terminal segments of the maxillary palps, and by usually having long and slender hind legs. Their coloration tends to be somber brown in nocturnal species, and bright, often metallic, in diurnal ones. Adults conform to a variety of morphological types. Most have elongate antennae that generally reach beyond the tip of the abdomen. Some mimic other insects, especially wasps, in which case the front wings tend to be greatly reduced to expose the membranous hind wings. Many are serious agricultural or forest pests. Depending on species, there are HH, WH, SH and DH relationships. Many adults are flower visitors or feed on tree sap. Eggs are laid in batches of, on average, 12 (Hanks 1999). The larvae possess gut symbionts.

The following are the better-known or economically more important species of Tanzania and neighboring areas.

Androeme plagiata Aur. occurs in the West Usambara Mts. where it co-exists with and plays a similar role as the overall more important *Oemida gahani* Dist. elsewhere (Gardner and Evans 1957; Duffy 1957, 1980). This beetle is found in dead wood of *Cupressus*, *Podocarpus* and *Juniperus*, but also in dead wood of living juniper. The adults are 11-27 mm long, dull olive-green and, unlike *O. gahani*, they have the prothorax without elevations and their antennal scape rounded. The mature larvae resemble those of *Xystrocera* spp. They differ from *O. gahani* by not having bi-lobed dorsal creeping welts (ampullae) and by having more pronounced legs (Gardner and Evans 1957).

Chlorophorus (=Caloclyctus) carinatus Aur. The larvae of this beetle are very common but relatively unimportant borers in dieing trees, stumps and logs of many hardwood and conifer species in the East African Highlands (Peake 1949; Duffy 1957; Gardner 1957a; Jones and Curry 1964). Initially the larvae were confused with those of *O. gahani*, from which they differ by having a distinctly blackish, anterior margin of the head, a pair of simple eyes, the legs indistinct and abdominal ampullae that are not bi-lobed (Gardner and Evans 1957). Also, unlike the wood-boring larvae of *O. gahani*, this species builds tortuous galleries typically in the inner bark (Plate 32), entering the sapwood with shallow tunnels only at the time of pupation (Gardner 1957a,b). Curry (1965c) did, however, consider it a potentially serious pest of cypress, because "the beetle has apparently adapted itself to life in living sapwood into which it penetrates from the dead wood of old rat wounds or cankers, or pruning scars". The total life cycle takes about six months (Gardner 1957a). The larvae which also attack coffee bushes, are considered human food at Kilimanjaro (Hemp 2001a). Another two species of *Chlorophorus* were reported on *Acacia* in Kenya (Gardner 1957a).

Cordylomera spinicornis F. This WH and SH species attacks mature living trees and recently felled logs of various species of mahogany (Duffy 1957, 1980). It frequently shows in timber yards from West through East Africa, Zanzibar and down to Malawi. Exported logs with intact bark are frequently heavily infested, but since damage is relatively superficial, this insect is not a major pest. Infested trees exhibit slight gum flow.

The adult beetle is 13-25 mm long. Since its color varies greatly, it has previously been described as several species. In all varieties the elytra are shining metallic to some extent. The legs are black with swollen, red femora. The antennae carry strong spines and in the male extend beyond the tip of the elytra (Figure 5-9). The spines are also prominent in the pupa.

Groups of about 30 eggs are tightly packed in fissures of bark. The larvae feed at first as engravers of the outer sapwood, later enter the outer 5 cm of sapwood, and

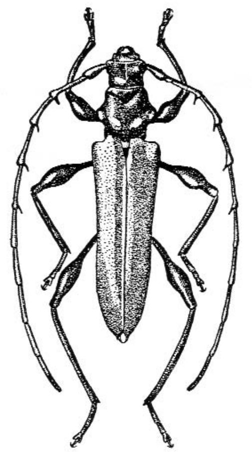


Figure 5-9. Cordylomera spinicornis (Cerambycidae), a relatively shallow borer in logs of mahogany. (From: Duffy 1957).

for pupation dip into the heartwood. Their development probably takes years.

Mecosaspis whytei Gah. This beetle occurs throughout the Afrotropics. In Tanzania it was recorded on living *Syzygium* spp. (Duffy 1980). The larvae are up to 58 mm long and resemble those of *Philematium.* This is probably a WH or SH species.

Neoclosterus boppei Q. & V. This is an economically important pest in West and East Africa (Duffy 1980). In East Africa, live and recently converted *Brachystegia spiciformis, Isoberlinia* and *Ficus* may be severely damaged. Attack results in copious gum flows and orange-red frass that is ejected from holes in the trunk and accumulates on the floor beneath. Flagging branches are common.

Duffy (1980) describes all stages of this beetle in great detail. The adult is a 34-47 mm long, dark brown or reddish beetle. The antennae are combed and do not reach beyond the basal fourth of the elongate, parallel-sided front wings. The mandibles extend forward and the pronotum carries stout, lateral spines.

Eggs are laid singly on the bark. The larvae initially tunnel vertically into the sapwood before entering the heartwood. Pupation takes place in a cell lined with coarse fibers. This is probably a WH or SH species.

Oemida (=Paroeme) gahani Dist. This is East Africa's best-researched longhorn beetle. It is ubiquitous in the Kenya Highlands, especially West of the Rift, as well as in several mountain areas of Tanzania (Kilimanjaro, Meru, Usambaras, Ngorongoro, Mbulu, Mufindi and Kibau). It has also been found at Ukerewe, a few sites in Uganda, Zimbabwe and in South Africa, the latter a questionable record (Jones and Curry 1964). It ranges at altitudes from 700-3,500 m, with an optimum between 2,300-3,000 m (Curry 1965b). A close relative of *O. gahani, Oemida impunctipennis* Duffy, is associated with hardwoods in Uganda, but is of little economic importance.

Before adopting certain exotic trees, *O. gahani* attacked many species of dead or injured indigenous, evergreen hardwoods and conifers. It is known to infest at least 173 species of trees representing 56 botanical families (Jones and Curry 1964; Duffy 1980). Among the 15, particularly common native hardwood hosts in Tanzania are *Olea hochstetteri, Trichocladus ellipticus* and *Celtis africana* (Jones and Curry 1964). While the hardwoods constitute the main reservoir of *Oemida,* the indigenous softwoods contribute to infestations to an extent that is out of all proportion to the numbers of host species and their occurrence. Importantly, only one of the indigenous

tree species, *Juniperus procera,* is attacked in both the living and the dead state. In this species, the attack occurs in the heartwood of trees up to about 50 years old but is confined to the sapwood in ageing trees. Susceptible exotic species other than cypress include *Acacia melanoxylon, Acrocarpus fraxinifolius, Grevillea robusta* and three species of eucalypts and pines (Curry 1965b). Pines do, however, suffer little damage. Cypress plantations are subject to different degrees of attack, depending on the numbers of infested indigenous tree stumps in the area or the proximity of plantations to natural forests (Curry 1965b).

This beetle's appearance as a serious menace to structural timber, especially the wood of podo (*Podocarpus* spp.) and other conifers, coincided with the growth of Nairobi and neighboring farms in the 1930s (Gardner et al. 1953). Its real impact, however, was only felt after the late 1940s, in conjunction with the extensive softwood plantations that had been established in the East African Highlands since the 1920s. These had relied to a great extent on monocultures of exotic *Cupressus benthami, C. lusitanica, C. macrocarpa* and *C. torulosa*, and to a lesser extent on indigenous *Juniperus procera,* all representing the family Cupressaceae. In the rainy, temperate highland climate over 2,000 m, these plantations initially grew very well and relatively trouble-free. However, as the cultures matured, they increasingly experienced problems with *O. gahani*. Living individuals of all species of *Cupressus*, as well as their dead wood proved highly vulnerable to this beetle (Jones and Curry 1964). In certain 26-year old plantations, 95% of trees were attacked. *O. gahani* avoids healthy softwoods, but trees injured by any agent, especially wildlife such as Sykes monkeys, buffaloes or elephants, and those that had been pruned, a routine cultural measure to improve timber quality, were selected for attack. The beetle prefers large and relatively fresh wounds (Curry 1965b). Since the larvae of *O. gahani* are restricted to the dead inner wood, trees attacked continue to grow, but the quality of the wood is greatly compromised. At least 14 species of exotic hardwoods, and some exotic softwoods other than cypress (*Araucaria* and pines) can also be attacked by *Oemida*, but not while alive (Jones and Curry 1964). Compared with the exotic softwoods, the exotic hardwoods are, however, of little importance as hosts for *Oemida*. This beetle's host relationships include WH, SH and DH types.

While once considered the economically most important longhorn beetle of East Africa (Curry 1965b), *O. gahani* has since lost much of that distinction. During the past decades, wildlife, the cause of many tree injuries, was eliminated from most conifer plantations in East Africa. More importantly, however, a recent epidemic by the exotic aphid *Cinara cupressivora* Watson & Vögtlin killed many remaining cypress, the preferred host of *O. gahani*, throughout East Africa. The history of *O. gahani* (and the aphid) nevertheless vividly reinforces multiple lessons learned worldwide concerning the dangers of extensive monoculturing.

The white elliptical eggs of *O. gahani* are about 1.3 mm long and granulate (Gardner et al. 1953; Gardner and Evans 1957). Several batches of usually less than 50, but occasionally more than 100 eggs, are cemented into cracks, crevices or

depressions of dead wood or on injuries of living hosts, for a total of up to 250 (Curry 1965b). In structural timbers, eggs are laid in old emergence holes. The incubation period varies from 5-9 weeks, but averages about eight weeks (Curry 1965b).

The grubs (Figure 5-10) have minute legs and distinctly bi-lobed dorsal creeping welts. A mature larva is from 20-42 mm long (Duffy 1957). A trace of pigmentation at the anterior extremity of the head differentiates it from most other cerambycids that share the same hosts. Ocelli are absent. The larval galleries are narrowly oval and packed with powdery frass. Tunneling remains externally invisible until emergence holes on the outside of dead wood reveal the activity of the borers within. By that time the heartwood of cypress or junipers, the only species attacked through pruning scars (Curry 1965b), may be intensely honeycombed by numerous larvae. Damage to other living indigenous and exotic species is confined to the dead wood below wounds. There is considerable variation in the length of the larval period both between larvae from the same batch and between larvae in wood of different species and moisture content. The shortest life cycle recorded, most of it in the larval condition, was 14-15 months in moderately moist cypress. In dry structural podo, larvae can live for perhaps ten years but then only produce miniature adults (Gardner and Evans 1957; Curry 1965b). In living cypress, the period from larval entry to beetle emergence seems to vary from 34-42 months (Curry 1965b). Much shorter periods, 12-13 months, have been recorded from dead *Maytenus undatus*.

Figure 5-10. Larva of *Oemida gahani* (Cerambycidae) in the heartwood of *Cupressus lusitanica.* March, Olmotonyi, Arusha.

The pupal chambers, containing a pupa that is up to 14 mm long, are found near the surface of dead wood (Duffy 1957). The newly hatched adult emerges through an oval exit hole some 6 mm in diameter, but never through living sapwood (Curry 1965b).

The beetles (Figure 5-11) are slender, dull brown to yellowish in parts and measure from 8-23 mm. The prothorax has a pair of short, blunt lateral tubercles. The beetle's antennae are reddish with the scape and tips of the following segment dark brown to blackish. Beetles emerge at dark throughout the year with two peaks in April and November, i.e., during the two rainy seasons. In males, the long antennae exceed body length, while they are shorter in females. Beetles are night-active, strong fliers and live generally for less than two weeks and up to one month (Gardner et al. 1953; Curry 1965b). They do not feed, are not attracted to light and seek shelter during the day (Curry 1965b).

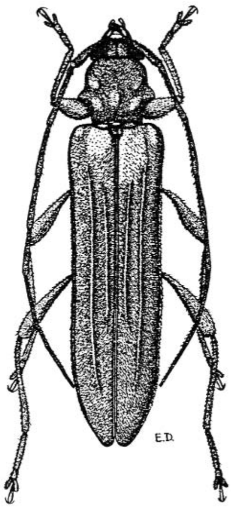


Figure 5-11. Female *Oemida gahani* (Cerambycidae). (From Duffy 1957).

During the heyday of plantation culture for cypress in the East African Highlands, the main strategies to deal with *O. gahani* involved physical, chemical and cultural control efforts (Gardner et al. 1953; Jones and Curry 1964; Curry 1965b). The removal, destruction or charring of stumps, dead trees and logs of all susceptible indigenous species in the planting area was considered of prime importance. Barriers between cypress plantations such as strips of pine or natural forests were considered useful, as were trap trees. The abolition of pruning, the chief cause of attack, was advocated or at least a halving of the standard pruning height to 5 m. Where continued, the pruning scars were to be treated with wound dressings such as car grease ("doping") and annual or biennial pruning was routinely employed to produce smaller and more rapidly occluding scars. Animal control by shooting of monkeys and electric fencing against large game also provided partial relief at least locally or temporarily. Burning of infested wood or kiln-drying, and pressure treatment of wood before installation were recommended to promote sanitation or to mitigate problems in structural timber. Eventually, many cypress plantations were clearcut and converted to exotic pines because live pines had proven immune to attack by *O. gahani* (Gardner and Evans 1957; Jones and Curry 1964).

Antagonists of the beetle include three families each of predatory beetles (Cleridae, Trogositidae and Colydiidae) and hymenopterous parasites (Braconidae, Stephanidae and Eupelmidae) (Gardner et al. 1953). These are, however, considered only mildly beneficial for the natural control of *O. gahani.* There is also evidence of a bacterial or viral disease of larvae (Curry 1965b).

Phoracantha spp.: *Eucalyptus Borers.* Originating in Australia, two species of eucalyptus borers, *Phoracantha semipunctata* (F.) and *P. recurva* Newm., have become moderate to severe pests in many parts of the world where eucalypts are cultivated (Booth et al. 1990; Duffy 1957; Millar et al. 2003). They were first detected in South Africa in 1906, having probably been introduced in freshly cut railway sleepers imported from Australia during the Anglo-Boer War (Cillié and Tribe 1991). They are now found throughout South Africa, and by the latter half of the 1960s had arrived in Malawi (Austarå 1969b; Esbjerg 1976) and in Zambia (Ivory 1977). The beetle supposedly occurs in Kenya and, although not documented for Tanzania yet, is likely to be present there too (J Moore, pers. comm.).

As their name intimates, these beetles damage eucalypts, although levels of colonization vary significantly between host species. In Malawi, *E. fastigiata* and *E. paniculata* were the most susceptible of 12 species of eucalypts tested (Powell 1978). Recently felled logs and slash, or stressed trees of any age are attacked. In Zambia, where the first serious outbreak took place in the early 1970s, up to 90% of drought-stressed eucalypts were killed by this beetle, making it appear "more menacing than termites" (Selander and Bubala 1983). However, in Malawi the beetles even abound where drought is rare (Powell 1978). Symptoms in live trees include gradual wilting of the top foliage, then discoloration and dieback. Usually, young trees are the first to suffer mortality.

Both larvae and adults of the two species are difficult to distinguish. *P. semipunctata* has always been the more dominant species in Africa, but recently *P. recurva* has been increasing and is heading North from South Africa (J Moore, pers. comm.). The beetles are 16-30 mm long. *P. semipunctata* (Figure 5-12) is slightly larger and darker, with a light-colored interruption on the elytra of a dark zig-zag pattern. A spur-shaped protuberance on the 3rd antennal segment is straight. *P. recurva* is yellower, especially the legs. It has a pale interruption on the elytra, with 1-2 dark blotches. The spur-shaped protuberance on the 3rd antennal segment is slightly curved backwards (Drinkwater 1975).

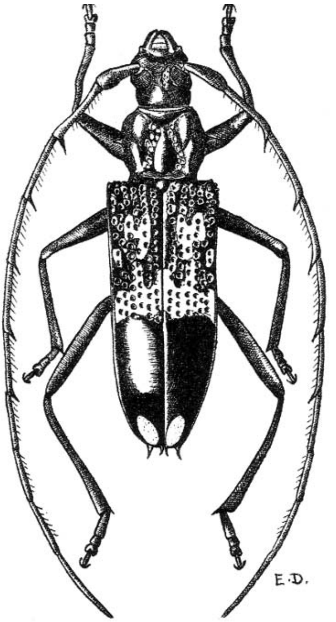


Figure 5-12. The eucalyptus borer *Phoracantha semipunctata* (Cerambycidae). (From Duffy 1957).

In Zambia, the night-active beetles fly and lay eggs throughout the year. Their activity peaks early in the warm season (late July to September) and again in November. The life history appears to be similar for both species, except that *P. semipunctata* usually oviposits in the lower stem of hosts, while *P. recurva* prefers

the crown. Eggs are laid in batches of around 20 (Cillié and Tribe 1991). The ovipositors are about 20 mm long when extended which allows eggs to be hidden deep in crevices or under bark scales. On fresh logs the first eggs appear within 48 hours of felling, i.e., first attacks happen on the second night. Logs remain suitable for egg laying from 2-3 weeks in Zambia (Löyttyniemi 1983), to about one month in Malawi (Powell 1982). The larvae hatch after 6-14 days and feed for 3-6 months in the subcortical region girdling the trees in the process (Duffy 1957; Austarå 1969b). The galleries may be straight or twisted and are tightly packed with frass. Pupation, which lasts about 10 days, occurs in the wood. In South Africa, emergence starts three months after oviposition in stems felled during the warm, dry season, but 4-7 months after oviposition in those felled at other times (Cillié and Tribe 1991). Developmental rates differ not only based on season, but also host species and size. On average, two or nearly three overlapping generations were completed in a year in Zambia (Löyttyniemi 1980, 1983). Adults feed on nectar and pollen and their longevity and fecundity is strongly affected by this diet. *Eucalyptus* pollen increases the longevity of *P. semipunctata* females by 48-71%, compared to other diets, and also that of males. Diet also dramatically affects fecundity. Females of *P. semipunctata* lay 4-8 times, and those of *P. recurva* 3-5 times more eggs on a pollen diet than on other diets (Millar et al. 2003).

Traditionally, control mostly relied on trap trees, debarking of logs, burning of infested material or avoidance of the most susceptible species of hosts (Löyttyniemi 1983). Biological control attempts involved the introduction of up to five hymenopterous parasitoids, but resulted in variable success in different parts of the world (Cillié and Tribe 1991; Moore 1995). The most promising among these was the egg parasitoid *Avetianella longoi* Sis. (Hym: Encyrtidae) which caused up to 90% parasitism in California (Hanks et al. 1996) and up to 70% in Australia and South Africa, encouraging more work along these lines (Moore 1995). This wasp was introduced and established in Zambia in 1995 (J Moore, pers. comm.). Natural controls are effective to some extent. The same gum that is attractive to the adults often drowns many of the first instar larvae (Duffy 1957). In Malawi, where densities of over 700 larvae/m^2 were counted, intra-specific competition from overcrowding accounted for most mortality of the older larvae (Powell 1982).

Philematium virens L. This large, green beetle attacks poles of *Manilkara* and *Casuarina,* used in scaffolding (Plate 33) along the East African coast and some of the Indian Ocean islands (Duffy 1957; Gardner 1957a,b). The larvae initially bore in the inner bark before entering and going deep into the wood. As a result, debarking poles before use is recommended.

Stromatium barbatum F.*: Teak Trunk Borer; Drywood Powderposter*. This beetle was presumably introduced to the East African coast during the 1950s when it was first discovered causing extensive damage to roofing timbers in a godown (Jones et al. 1966). It is distributed in Myanmar, India, Pakistan, Sri Lanka, Mauritius, Nepal and Madagascar, where it commonly occurs in structural timber, packing cases,

furniture, plywood and dead wood in the forest. While seasoned hardwoods are preferred, dry conifer timbers and bamboo are also included in a list of over 350 species of hosts. It has also been intercepted in other parts of the world, including Europe and New Zealand (Duffy 1957).

The white, ovoid eggs (2 mm), averaging 100 per female, are laid in small holes or cracks on rough surfaces of the host wood. The larvae have a reduced head and tiny legs. They grow to a length of 38 mm (Gardner 1927). The larval tunnels are tightly packed with powdery frass some of which is ejected at intervals. Adult beetles are 12-28 mm long, reddish-brown to almost black and are covered with fair hair. The antennae of males extend to about 1.5 times the length of the body.

Xystrocera spp. Some of the eight species in this genus reported from East Africa (Gardner 1957a), at least four of which occur in Tanzania (Duffy 1957, 1980), are considered pests of consequence (Jones and Curry 1964). Hosts most often include *Acacia*, other legumes and *Celtis*, but logs of some other hardwoods are also listed (Duffy 1957, 1980; Gardner 1957a).

2.4.4. Lamiinae

With more than half the species, this is the largest subfamily of Cerambycidae. There are numerous representatives in Tanzania as reflected in the fact that one expedition to Tanzanian mountain forests alone yielded 117 species including 11 new ones (Basilewsky and Leleup 1960). One collection of Lamiinae from Tanzania, Zambia and Botswana included 292 species, 86 new to science (Forchhammer and Breuning 1983). While these were only collection records, Gardner (1957a) lists 127 species with host trees for East Africa (34 species for Tanzania), and Le Pelley (1959) added another 30 species in East Africa (24 species in Tanzania) including agricultural and notably many coffee pests (Kolbe 1911). Some of the mono- or oligophagous species are candidates for biological control of certain weeds, including weedy trees.

Most of the Lamiinae are WH, SH or DH borers overwhelmingly in the inner bark and wood of hardwoods. Some of the WH and SH species often kill smaller trees. On the other hand, shoot borers and girdlers are HH species that generally only disfigure trees. Other species of Lamiinae include gall formers, and some attack seed of trees or develop in herbaceous hosts.

The beetles are short oval to greatly elongate and from 2-80 mm long. Nocturnal species tend to be somber black to brown or grey, while diurnal ones are often brightly colored. The antennae are of variable length and the hind legs are usually short. Most characteristic is an oblique groove on the inner side of the tibiae of the first leg. The head is more or less vertical in the front or the mouthparts point slightly backward. The apical segments of the palps generally taper at the tip.

Behaviorally, the Lamiinae are unique among Cerambycidae (Hanks 1999). They lay 25 eggs per egg niche on average (Hanks 1999). While other longhorn beetles use

cracks to lay their eggs in, the Lamiinae gnaw egg niches into the bark or stem of hosts and cover the eggs with a protective substance. Also, unlike others, the adults appear to require maturation feeding for which they select foliage, tender bark or shoots. There are no gut symbionts.

The following are the better-known or more important Lamiinae of Tanzania and neighboring areas.

Paranaleptes (=Analeptes; Diastocera) reticulata (Thoms.): *Cashew Stem Girdler.* This beetle occurs commonly from Ethiopia to Tanzania and occasionally causes severe damage in coastal areas (Duffy 1957). It girdles branches 30-80 mm thick with a v-cut (Plate 34), which leads to their breakage. *Ceiba* and probably all other wild Bombaceae are hosts, together with *Casuarina, Citrus, Ficus,* indigenous species of *Acacia*, and, where it is a major pest, cashew (Gardner 1957a; Hill 1983). Excessive girdling of branches can kill young trees (Harris 1938; Duffy 1957, 1980; Gardner 1957a). A related species, *P. trifasciata* F., is a girdler of *Eucalyptus globulus* in Kenya and of *Lannea* in Uganda (Le Pelley 1959).

The beetles are 25-35 mm long. The head and thorax are entirely covered with brownish pubescence. The front wings have numerous black granules surrounded by dark brown patches, giving a reticulate appearance (Duffy 1957). The antennae slightly exceed body length in the female and more so in the male.

The 5 mm long, elongated eggs are laid singly in transverse slits made in the bark of the distal portion of a girdled branch. The yellow larva, which bores in the girdled branch, may attain a length of 45 mm fully grown. Pupation takes place in a cell in dead wood (Hill 1983). The total life cycle takes one year and adults are active from May to October.

For control, it is recommended to collect and burn the broken branches in November and December.

Phryneta (=Inesida) leprosa F.: *Castilloa Borer.* This beetle is widely distributed in the Africotropics where it attacks mostly Moraceae and Ulmaceae. Hosts include *Antiaris, Bosqueia, Castilloa, Celtis, Chaetacme, Chlorophora excelsa, Morus* spp., *Hevea brasiliensis* and *Holoptelea* (Gardner 1957a; Le Pelley 1959; Mshiu and Kisaka 1983), but many more species are affected in other parts of Africa (Brunck 1965; Duffy 1980). While this insect usually attacks felled or unhealthy trees, living hosts are also subject to attack. The larvae make wide galleries under bark before boring deeply into the sapwood. Serious damage has occurred to young *Chlorophora* in the Congo and other parts of West Africa, often followed by fatal rot, and logs of *Chlorophora* have been damaged considerably elsewhere (Gardner 1957a; Jones 1957). *P. leprosa* killed *Castilloa* at Amani, and in Cameroon the planting of this species was discontinued, after entire plantations of this tree were destroyed by this beetle (Morstatt 1911b, 1912c). While the larvae are woodborers, the adult beetles also cause damage by browsing on the bark, shoots and foliage of

succulent twigs of *Chlorophora, Ficus* and presumably other species (Wagner et al. 1991).

The beetle (Figure 5-13) is 20-42 mm long and is entirely covered with a light brown pubescence, except for a few darker brown patches (Morstatt 1912c). The antennae of males are about one and a half the length of the body, while those of females are shorter than the body. The prothorax is armed with a pair of large, slightly curved lateral spines. During the night, the beetles insert 40-50 eggs singly into egg niches chiseled into the bark of hosts. Young larvae initially bore in the subcortical zone, but later move into the sap- and heartwood, where they pupate. Mature larvae are up to 55 mm long.

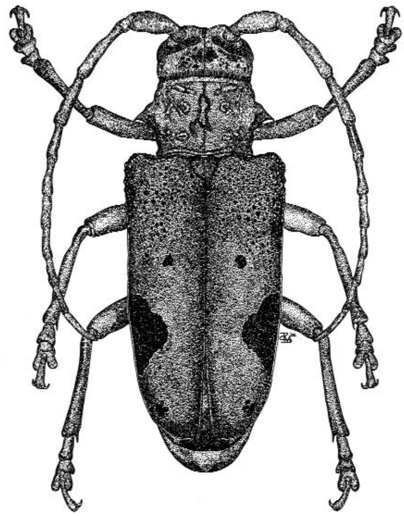


Figure 5-13. Female castilloa borer *Phryneta leprosa* (Cerambycidae). (P. Schroud).

The beetle rarely attacks trees in deep shade, and the pupae are subject to attack by the larvae of a large species of wireworm (Elateridae) (Duffy 1957).

Several other species of *Phryneta* occur in East Africa. All are collector's items. Little more than a few hosts is known about most (Gardner 1957a; Basilewsky and Leleup 1960; Forchhammer and Breuning 1986), except *Phryneta spinator* F., the fig tree borer. This species occurs on *Artocarpus, Bauhinia, Cupressus* and *Ficus* spp. in Kenya (Duffy 1957, 1980; Le Pelley 1959) and in South Africa is a serious pest of *F. carica* and *Salix* (Scholtz and Holm 1985). It lays eggs in batches of four into the bark, the larvae hatch after 10-18 days, and the beetle emerges about two and a half years later.

Prosopocera brunneus Br.*: Isoberlinia Borer.* First reported by Jones (1965b) and later summarized by Duffy (1980), *P. brunneus* attacks living *Isoberlinia scheffleri* in Tanzania, severely degrading the wood, however, without killing the tree. In parts of the Eastern Usambaras, 87% of hosts were infested seriously enough to discourage the culture of *I. scheffleri* in that region (Jones 1965b). Trees are first attacked when between 30-60 cm in girth, and attacks continue for the rest of the life of the tree. Several smaller species of *Prosopocera* also occur in Tanzania (Möbius 1898; Basilewsky and Leleup 1960; Duffy 1980) and four new species were reported fairly recently (Forchhammer and Breuning 1986).The large genus *Prosopocera* includes many attractive beetles throughout Africa sought by collectors.

The beetles are over 50 mm long, while the larvae may be 127 mm in length. The female lays single eggs in bark, starting at ground level and continuing up to larger

branches in the crown, with a preference for the lower 7 m. As larvae bore into the sapwood, copious gum and sap flow out of the entrance holes. The larvae keep these holes open and even enlarge them to be able to eject pellets of frass (Duffy 1980). The decomposing exudations create a pungent, nauseating odor. Advanced instars are generally confined to the heartwood. Eventually, after building an exit tunnel to just below the bark, the larvae plug the entrance to their pupal chamber at both ends with large fibers. The adult flight hole is about 45 cm or more above the original entrance hole and develops into a knot after occluding. The beetles are attracted to light. The entire life cycle probably takes one or more years.

Thercladodes kraussi White *(=Cloniocerus kraussi): Sombre Twig Pruner.* This beetle was reported from Madagascar, South Africa, Mozambique and Angola, as well as from the West Usambaras where it attacked living shoots of *Olea chrysophylla* (Duffy 1957; Gardner 1957a). It attacked various other Oleaceae, especially *Fraxinus,* in South Africa, and in that country was also very destructive to *Ligustrum* hedges. Damage intensified from year to year as the beetles laid eggs in the same plants they had emerged from. In Tanzania, damage apparently remained insignificant.

The beetle's appearance and natural history in South Africa were documented in great detail (Fuller 1913). The beetle is a fairly hairy, funereal black, except for broad patches of buff on each side of the thorax and a wide band of the same hue, speckled with red, across the distal portion of the elytra. The thorax bears four conical projections. Most remarkable are the tip-curled antennae, which consist of segments of varied shapes and lengths. The third segment bears a conspicuous plume-like bunch of hairs. The anterior part of the elytra is marked by tufted humps, and there are also numerous tufts in the posterior portion. The larvae are elongate, slender, cylindrical grubs up to 26 mm long.

In South Africa the grubs were found throughout the year and beetles hatched over several months. The eggs are inserted in niches cut into lush, thin shoots, 11-30 cm from the tip. The larvae hatch after about 12 days, and, at first, bore up in the branch then downwards, ejecting frass from a series of vent holes. The tips of branches in which the grubs live eventually flag and often break off.

Control simply relied on physical removal and destruction of infested shoots.

Tragiscoschema spp.*: Longhorn Shoot Borers.* This genus includes six species in Africa, including five *(T. amabile* Perr., *bertolinii* Thoms., *elegantissimum* Breun., *inerme* Aur. and *nigroscriptum* F.) in Tanzania (Breuning 1934; Forchhammer and Breuning 1983). Hosts listed for these beetles include *Acacia clavigera,* cotton, *Bombax, Ceiba pentandra, Khaya* spp., *Sterculia, Terminalia* and *Dombeya rotundifolia* (Breuning 1934; Duffy 1957; Jones et al. 1965a).

Morphologically, this genus of mostly yellow and black beetles, resembles *Tragocephala* but differs in that the two eye lobes are completely separated in *Tragiscoschema* beetles. The general biology of the two genera is considered similar,

except that, in the process of constructing a pupal cell, the last instar larva of *Tragiscoschema* partially severs the stem not only at a point above the pupal chamber, as do *Tragocephala*, but at a point below as well. A fiber plug is placed at each point of severance, presumably to discourage intruders when the stem later breaks at one or both points (Prosser et al. 1965).

Tragocephala spp.*: Longhorn Shoot Borers.* This closely related and equally colorful genus, with at least 22 species, is widespread throughout sub-Saharan Africa and Madagascar (Breuning 1934). At least six species (*T. mima* Thoms., *mixta* Breun., *modesta* F., *morio* Jord., *nobilis* F. and *variegata* Bert.) occur in Tanzania, the latter two being the most common. *T. nobilis* (=*T. pretiosa* Hintz) occurs from West through Central and East Africa to Angola and Malawi, while *T. variegata* is distributed from Ethiopia to Natal and Angola, including Zanzibar and Madagascar (Duffy 1957). These insects have at times caused serious and extensive damage in conjunction with trial plantations of indigenous and exotic hardwoods, including *Albizia* spp., *Bombax rhodognapholon, Calliandra calothyrsus, Cassia* spp., *Cedrela odorata, Cephalosphaera usambarensis, Cinnamomum camphora, Citrus* spp., *Cajanus cajan, Coffea, Dienbollia* spp., *Fagara usambarensis, Gossypium* spp., *Khaya* spp., *Mangifera indica, Maesa lanceolata, Ocotea usambarensis, Persea americana, Prunus domestica, Samanea saman, Terminalia* spp., *Theobroma, Toona* and *Vigna unguiculata* , among others (Morstatt 1912a, d; Gardner 1957a; Le Pelley 1959; Jones et al. 1965a, b; Prosser et al. 1965; Mshiu 1969; Duffy 1980). Many of these hosts are valuable trees or other desirable crops. *Tragocephala* are now also increasingly impacting trees in agroforestry.

The beetles are 17-26 (to 40) mm long and boldly marked in black and yellow. *T. nobilis* has distinct alternate black and yellow, transverse bands on the elytra and a broad black band down the middle of the prothorax. *T. variegata* (Figure 5-14; Plate 35) has predominantly yellow elytra with irregular black spots and patches. The broad black in the center of the pronotum is divided into two bands by a central yellow stripe (Mshiu 1969). The larvae (Figure 5-15A) are legless grubs with prominent ampullae or ambulatory welts on the back and lower side that allow them to creep through their galleries. Larvae of different species of *Tragocephala* are difficult to differentiate. Advanced instars are about 45 mm long, pale white, elongate and subcylindrical with a maximum width at the prothorax of about 7 mm in a grown specimen. Pupae are yellow (Morstatt 1912a).

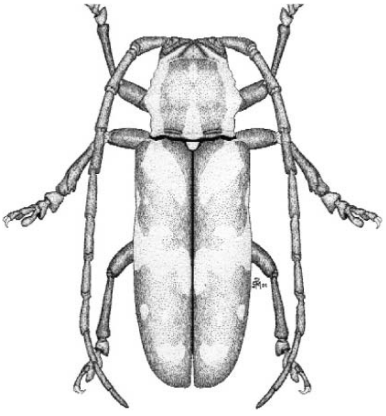
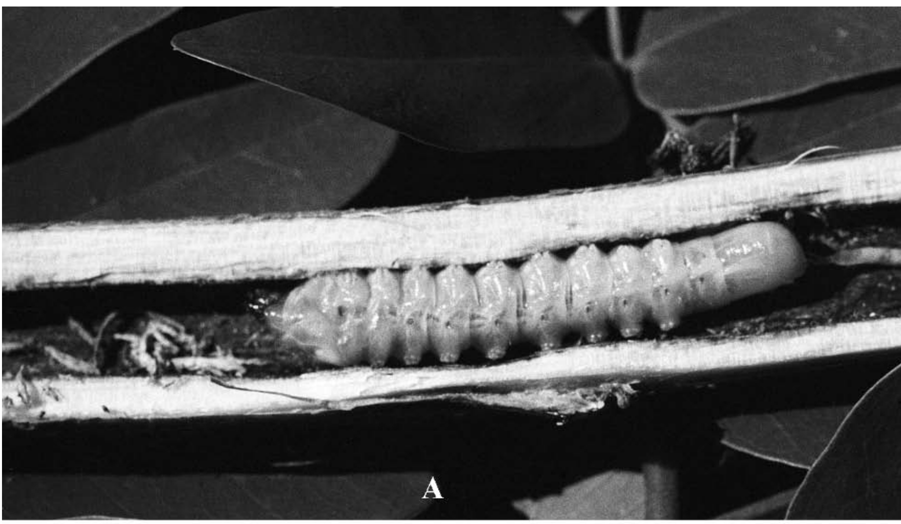


Figure 5-14. The longhorn shoot borer *Tragocephala variegata* (Cerambycidae). (P. Schroud).

In preparation for oviposition, a female (sometimes assisted by a male) typically girdles young succulent terminal and lateral shoots 5-10 cm below the tip (Figure 5-15B). She then lays a single egg in a slit immediately above the girdle or into the girdle (Morstatt 1912a,d). The egg hatches after about 7-10 days. The newly emerged larva first feeds on the eggshell, then bores into the center of the dying stem and later feeds downward into the pithy center of the green shoot below the girdle, but also into the wood. At intervals the grubs cut vent holes (Figure 5-15C) through the bark of the stem to eject some frass and allow gums produced by the tree to escape. They continue feeding there for a year or more, by which time the gallery may extend 1 m or more into the stem. When fully grown, the larva excavates a pupal chamber, closes it off with a fibrous plug, and immediately severs the life-supporting tissues of the



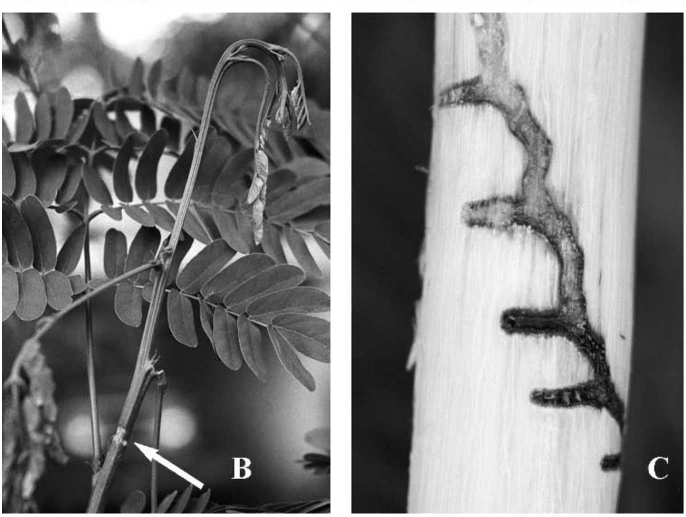


Figure 5-15. The longhorn shoot borer *Tragocephala* sp. (Cerambycidae) attacking *Albizia lebbeck.* (A) Larva in branch (B) Succulent shoot partially girdled (arrow) in preparation for oviposition. (C) Lateral galleries connected with vent holes. December, Morogoro.

stem from the inside to several inches above the pupal cell. Eventually, the severed stem withers, dies and drops, exposing the fiber-filled gallery. After about 1-2 months, the adult beetles hatch, but only emerge from the chamber after another week. The beetles feed on shoots and foliage of hosts, but compared to girdling and boring of the larvae, this damage is minor. Death of the branch tips and terminals leads to secondary shoots and disfigured stems, resulting in log degrades. Repeated attacks also reduce the tree's vitality and competitiveness. In Tanzania the life cycle for *T. nobilis* is two years (Morstatt 1912a,d; Duffy 1980). Field and glasshouse experiments conducted there with *Tragocephala* showed that on some hosts, such as *C. odorata,* attacks and shoot damage from the mother beetles may be heavy, without the larvae fully developing though (Jones et al. 1965b). On the other hand, attacks on *Bombax* were almost always successful. In Zanzibar, adults of *Tragocephala* are prevalent from October to March (Mansfield-Aders 1919/20). In the Usambaras, flagging branches and pupae occur in August, beetles are present in November, and large larvae can be found at the beginning of the year (Morstatt 1912a).

Chemical control is considered difficult, and biological controls have not been investigated in depth. Removal and destruction of infested twigs and branches in January/February are considered effective measures (Morstatt 1912a, d).

Miscellaneous other Lamiinae include the following representatives:

Ceroplesis spp. At least 10 species of this genus occur in Tanzania (Gardner 1957a, Le Pelley 1959; Forchhammer and Breuning 1986; Duffy 1980). Tree hosts are mostly legumes (*Acacia*, *Albizia*, *Cassia*), but include others (*Celtis, Chlorophora excelsa* and *Lannea*).

Coptops aedificator F. is a common bark borer in numerous dead trees such as *Afzelia, Ficus*, and *Manihot glaziovii* from West to South Africa, but is not considered important (Duffy 1957; Gardner 1957a; Le Pelley 1959).

Jordanoleiopus gardneri Br. seems to be the only beetle in this group to have been discovered under the bark of a conifer (*Cupressus*) in Tanzania (Gardner 1957a).

Monochamus, a cosmopolitan genus, includes at least three species in Tanzania with no host records available (Duffy 1957, 1980). *M. griseoplagiatus* Thoms. was recorded from several mahoganies, coffee, *Canarium, Cynometra, Celtis, Lachnopylis* and *Maesopsis* in Uganda (Le Pelley 1959).

Opepharus spectabilis Perr. occurs under the bark of *Croton, Olea welwitschii* and *Sterculia* in Tanzania, where it may kill smaller trees. (Duffy 1957; Gardner 1957a; Le Pelley 1959).

Phantasis and *Trichophantasis* are represented with one species each in Tanzania (Sudre and Teocchi 2000). These beetles are slow moving, large, armored beetles

somewhat resembling weevils (Figure 5-16). Larvae are supposedly eating grass roots, but the biology of these beetles appears uncertain. They are coveted as specimens by collectors.

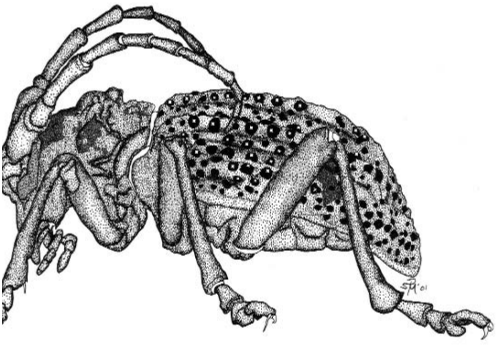


Figure 5-16. Phantasis sp. (Cerambycidae), a non-flying longhorn beetle. (P. Schroud).

Sternotomis bohemani Chevr. occurs from South to East Africa. Larvae feed in the logs of *Antiaris* and *Chlorophora excelsa* (Gardner 1957a; Le Pelley 1959).

2.4.5. Prioninae

While not the largest subfamily of Cerambycidae, this group always captures the attention of nature lovers because many of the species are very large. Being nocturnal, these beetles frequently buzz lights like mini-bombers. The world's two largest beetles, both from tropical America, are up to 150 mm long and belong to this group. African species, while not quite as big, are still impressive and receive a high degree of attention from collectors (Lameere 1903; Gilmour 1956a,b; Quentin and Villiers 1978; Santos Ferreira 1980).

As a group, the Prioninae are medium to very large, mostly dull brown to black, somewhat flattened beetles with impressive mandibles projected forward to oblique. The transverse, flattened pronotum has distinct lateral margins often with sharp spines. The thread-like or serrate antennae are less than body length and inserted fairly close to the bases of the mandibles. Intriguingly, different genera living in different parts of the world have strikingly similar appearances. The grubs do not have gut symbionts. They usually live in rotten, moist wood in the roots and trunks of many dead hardwoods (Plate 36), but rarely in conifers. Some species do, however, attack apparently sound or dry wood in living and declining trees, as well as in structures (Gardner 1957a,b).

There are at least 23 species of Prioninae in East Africa (Gardner 1957a; Le Pelley 1959). Although only seven were listed for Tanzania, there are certainly more. Only four of the better-known genera in East Africa will be dealt with here.

Acanthophorus spp.*: Giant Longhorn Beetles.* As their common name implies, these beetles (Figure 5-17; Plate 37) are massive, reaching 55-90 mm in length. They are

dark brown and covered with mats of fawn-colored hairs that rub off over time. The pronotum is bordered by 2-3 lateral spines, and the mandibles are very robust. They are night-active and attracted to light. The beetles lay eggs on dead trees and the larvae pupate in the sapwood. The adults feed on the leaves of a liana (Duffy 1957).

Three species in this genus were recorded for East Africa (Gardner 1957a, Le Pelley 1959). *A. confinis* Lap. is found on eucalypts and, in South Africa, on various Anacardiaceae (Lameere 1903; Picker et al. 2002). *A. maculatus F.* occurs in *Cupressus* spp. and in *Pittosporum* with heartrot, and *A. spinicornis* F. in decaying *Antiaris, Lophira, Phialodiscus* and *Sapium ellipticum.*

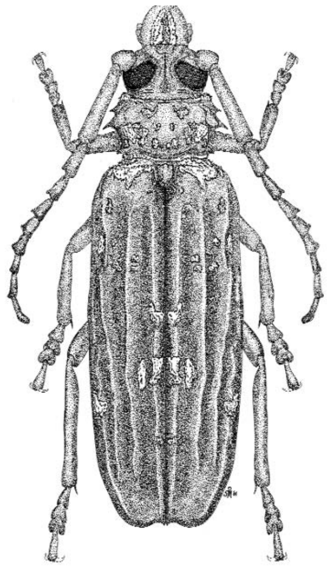


Figure 5-17. The giant longhorn beetle *Acanthophorus* sp. (Cerambycidae). (P. Schroud).

Macrotoma spp.*: Large, Brown Longhorn Beetles.* This genus of large, reddish, brown to black beetles is very widely distributed in Africa. Thirteen species and their hosts were listed for East Africa (Gardner 1957a; Le Pelley 1959), of which at least five occur in Tanzania. Although the beetles breed primarily in dead, dried and decaying trees, mostly hardwoods, some also attack live and declining trees, and some occur as well in sawn timber and wooden structures (Santos Ferreira 1980). Live trees attacked are usually weakened, but are not necessarily killed (Gardner 1957b). The mostly nocturnal beetles are attracted to light. During the day they hide under bark, on branches or under rocks.

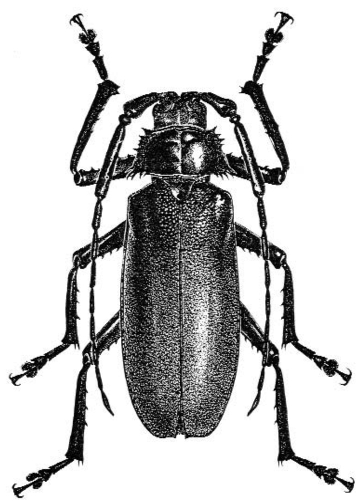


Figure 5-18. Male *Macrotoma palmata* (Cerambycidae). (From Santos Ferreira 1980; reproduced by permission of National Museum Bloemfontein, SA).

The best-known representative of this genus is *M. palmata* F., a 25-74 mm long beetle (Figure 5-18). It is a timber pest widely distributed not only through the Afrotropics, but as far as Morocco and Egypt (Santos Ferreira 1980). The beetles fly throughout the year, in Tanzania more so at the beginning of and during the rainy season (Gardner 1957b). The 4-5 mm long eggs are laid near the roots, cemented

together in batches (Duffy 1980). On Zanzibar, *M. palmata* was a serious pest in the mangrove wood rafters in local huts, and once damaged a piano case (Mansfield-Aders 1919/20). Larvae of the robber fly, *Proagonistes praedo* Aust., feed on the larvae of *M. dohertyi* Lmr. (Gardner 1957a).

Parandra gabonica Thoms. This member of an odd and primitive genus of the Cerambycidae differs from others in the family by having clearly 5-segmented tarsi, since the third segment is not bi-lobed and does not conceal the fourth segment. As a result, they are sometimes considered a separate subfamily of Cerambycidae, the Parandrinae (Scholtz and Holm 1985).

P. gabonica is a fairly common, 10-25 mm long, brown to pitch-black, elongate, moderately robust beetle (Figure 5-19) in most of tropical Africa, including Tanzania (Lameere 1903; Gilmour 1956a). For a cerambcyid, the beaded antennae are very short. Larvae of this beetle were found in a large log of *Celtis durandi* in Kenya, some in the harder part of the wood, others in rotten pockets (Gardner 1957a). Other hosts include *Albizia, Antiaris, Chaetacme, Funtimia* and *Schefflera* (Duffy 1957). Successionally, this beetle can best be classified as belonging to stage III (Eidmann 1943).

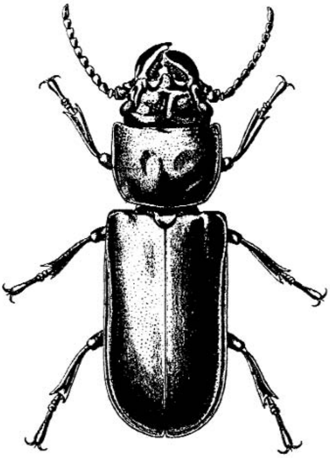


Figure 5-19. Parandra gabonica (Cerambycidae). (From Lameere 1903).

Stenodontes (=Mallodon) downesi (Hope). This beetle is widely distributed throughout the afrotropical and Madagascan regions (Duffy 1957). It was of considerable economic importance in *Hevea* in Zaire, attacking sound wood and causing trees to break in wind (Morstatt 1942). It has also been found in a great number of woody crop trees such as kapok, cacao, coffee, ceara rubber and coconut (Lepesme 1947; Duffy 1957, 1980). In East Africa it has occasionally been associated with injured, weakened trees, but is mostly found in dead or decaying wood from a variety of trees, including *Acacia mollissima, Antiaris,* coconut, *Croton, Ekebergia, Manihot glaziovii* and *Parinari* (Morstatt 1912c; Gardner 1957; Le Pelley 1959). Still, this beetle is not considered a big pest.

The beetles are 33-65 mm long, dark brown to black, smooth and shining (Figure 5-20). They have huge, curved mandibles but the antennae are relatively short for the family. The larvae are up to 85 mm long and eject coarse fibrous frass from their tunnels.

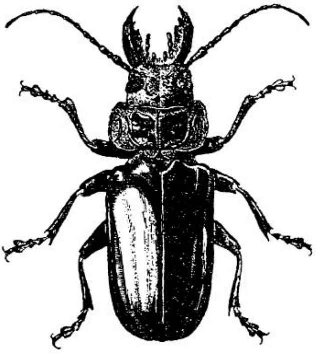


Figure 5-20. Stenodontes downesi (Cerambycidae). (From Morstatt 1912c).

2.5. Curculionidae: Wood-boring Weevils

As already mentioned in conjunction with defoliating weevils, there is virtually no tree part that is not affected by specific weevils. As a result, it is no surprise that there are also weevil borers in living and dead wood.

2.5.1. Mecocorynus loripes Chevr.*: Cashew Weevil*

As its common name implies, the main host of this weevil is cashew, but it also attacks living *Afzelia quanzenzis* (Evans 1960; Hill 1983). It is a minor pest in the coastal area from Kenya to Mozambique, as only severe attacks result in the death of hosts. This weevil is about 20 mm long and dark grey-brown. It is not known to fly. Eggs are laid singly in bark. The larva, a legless grub, bores through bark and feeds on the outer sapwood. Frass, mixed with gum, is ejected to the outside through small holes and may stick to the bark as a brown-black mass. The pupal chamber is about 20 mm below the bark, the exit tunnel plugged with woody fragments. The complete life cycle is about six months.

2.5.2. Miscellaneous Deadwood Weevils

Numerous weevils are associated with dead wood, as reflected in a long list of species and hosts on which they were found (Gardner 1957a, b, d; Le Pelley 1959). Although common, they are not nearly as important as ambrosia beetles. Some are space parasites of ambrosia beetles, but the nature of their association is not clear (Gardner 1957d; Löyttyniemi and Löyttyniemi 1987b). Some feed in the bark of declining or dead trees before pupating in wood. Most are found in logs that have been lying on the forest floor for months.

Most common among these weevils are *Stenoscelis* spp., with at least five representatives in Tanzania. Their presence in wood generally indicates fungal decay (Gardner 1957a). Many species of trees are attacked, including hardwoods and conifers. Next to the long-horned beetle *O. gahani*, these weevils were the most common borers found in tree wounds caused by large game in Kenya (Holloway 1964).

In Zambia, wood-boring weevils start flying with the rains and occur throughout the rainy season (Löyttyniemi and Löyttyniemi 1987b). Few are active during the dry season.

2.6. Lyctidae: True Powderpost Beetles

This small family of about 70 species of wood borers includes a few widespread species in East Africa. The beetles are commonly encountered in timber yards, wood shops, tools, furniture and structural timbers, mostly attacking partly or fully seasoned hardwoods of many species and occasionally conifers. Their destructiveness to wood and wood products is considered second only to that of termites (Jones et al. 1966).

These beetles are closely related to the false powderpost beetles (Bostrichidae), with which they share similar appearance and habits. Some taxonomists actually consider the lyctids a subfamily of the bostrichids. Both beetle groups require starchy sapwood for food, and they may occur together in the same wood.

Lyctids are smaller than most bostrichids, i.e. only 2-7.5 mm long and more flattened. They are parallel-sided, reddish-brown to black, covered with setae or scales and the last two segments of the antennae are enlarged into a club. Their tarsi are 5-segmented, the first segment very small and the fifth almost as long as the preceding ones together.

Unlike some false powderposters, lyctids always lay their eggs with a very long and narrow ovipositor from the outside of the wood, usually in the cut end. Large-pored woods such as *Grevillea robusta* are the most susceptible. There are only larval galleries. The beetles are night-active and are attracted to light.

The standard recommendation for control or prevention of lyctid damage includes heat treatment, fumigation, sanitation, and chemicals for surface or wood treatment (Peake 1949; Gardner 1957b; Jones *et al*. 1966). *Tarsostenus univittatus* Rossi (Col: Cleridae), preys on lyctids and other small wood-boring beetles (Gardner 1957a).

2.6.1. Lyctus brunneus (Steph.)

This species is by far the most destructive of the lyctids in East Africa (Gardner 1957b). It is a very common cosmopolitan, causing much damage to structural wood of many species (Gardner 1957a,b; Beeson 1961). Its appearance conforms to the general description for the family (Figure 5-21A). The white, translucent, cylindrical eggs hatch in 2-3 weeks and the grub tunnels through the wood, reducing it to a tightly packed, flour-like frass. Depending on the moisture and starch content of the wood, development takes about 10 months, but extreme temperatures will slow or speed up development. Optimum growth occurs in seasoned wood with about 15% moisture content. The mature larva (Figure 5-21B) is about 5 mm long, slightly curved and has a swollen front end. Its thoracic legs are short and the 8th

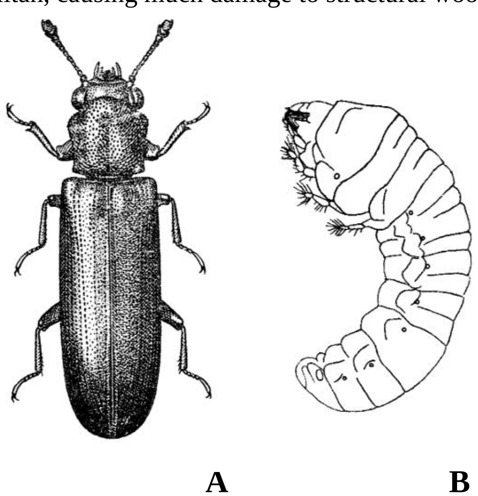


Figure 5-21. The powderpost beetle *Lyctus brunneus* (Lyctidae). (A) Adult (B) Larva. (From Gardner 1957b and Lesne 1924, respectively).

abdominal segment carries a pair of enlarged spiracles. Pupation occurs just below the surface, and in warm conditions the beetle hatches within a month. It escapes to the exterior through a small round hole (diameter of 1-1.5 mm) and in the process expels some sawdust. There may be 1-3 generations per year (Gardner 1957b). The total life cycle takes from seven months to three years (Skaife 1979).

2.6.2. Minor Lyctids

Lyctus hipposideros Les. occurs from Senegal through East to South Africa (Lesne 1924). Larvae of this beetle are found in sawn podo and dead branches of *Teclea* in East Africa (Gardner 1957a).

Minthea rugicollis (Walker), a tiny 1.8-3.5 mm long beetle, is also a pantropical pest common along the East African coast (Gardner 1957a,b). Besides corncobs it attacks a wide variety of woods and, most commonly, floor boards and roof timbers that have been in place for about nine months (Beeson 1961).

2.7. Lymexil(on)idae: Shiptimber Beetles

This is a small family of about 70 species of mostly tropical wood borers, with few African representatives. None is a major forest pest in continental East Africa and their biology is poorly known.

2.7.1. Atractocerus brevicornis L.

This widespread species in Africa is frequently observed at lights. The larvae occur in various hardwoods, including *Anacardium occidentale, Baikiaea, Ekebergia ruepelliana, Lovoa browni* and *Milbraediodendron* (Gardner 1934,1957a; Le Pelley 1959). They are reported to feed on a symbiotic fungus, introduced by the adults and growing in their tunnels (Skaife 1979). The adult (Figure 5-22) is an odd representative of the Coleoptera and thus frequently not recognized as a beetle. Its brown body is narrow and elongated. The front wings are reduced to two scales covering only part of the midthorax. While at rest, the membranous hind wings are folded fan-like over the abdomen, covering little more than half its length. The size of the beetles varies from 15-45 mm.

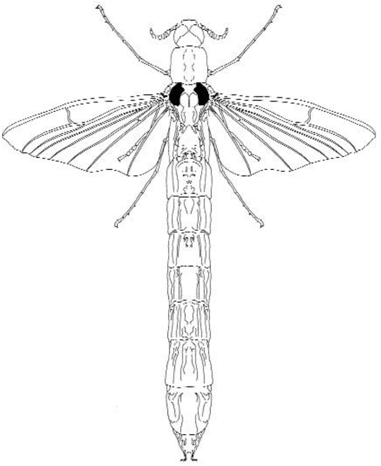


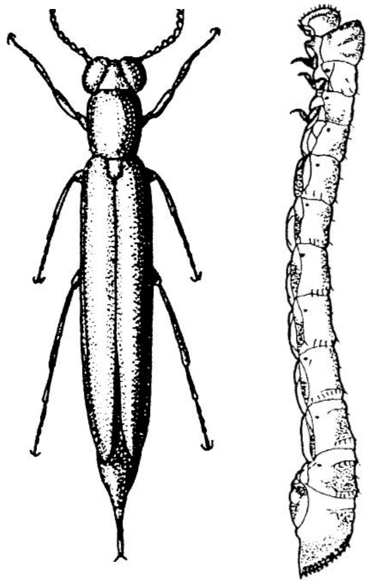
Figure 5-22. The shiptimber beetle *Atractocerus brevicornis* (Lymexilidae). (P. Schroud).

An Australian species, *Atractocerus kreuslerae* Pasc., caused more damage to commercial timber growing in parts of that country than any other insect (Clark

1925). As very little information exists about *A. brevicornis* in Africa, this Australian species may serve as a possible model. It mostly breeds in certain species of injured eucalypts, but also old stumps or old logs of other species. The elongate larvae are characterized by an enlarged, squarish prothorax, rudimentary legs with one sharp claw and a scoop-like abdominal tip. External evidence of this borer includes long thread-like cores of frass that project several centimeters from the burrow before breaking off and accumulating beneath. The pupal chamber lies close to the surface and, at emergence, the adult flies off instantly and with remarkable speed. The larval state takes at least two years to develop.

2.7.2. Melittomma africana Thoms.

This more typical beetle with saw-like antennae (Figure 5-23A) and its larvae (Figure 5-23B) are associated with logs of *Entandrophragma*, *Rinorea* and *Trema* in Tanzania and Uganda and other parts of Africa (Gardner 1957a). A close relative, *M.* (=*Promelittomma*) *insulare* F., is a "pest of the first magnitude" of coconut in the Seychelles and northwestern Madagascar, where it also occurs in a few endemic, native palms (Vesey-Fitzgerald 1940).



A **B**

Figure 5-23. (A) *Melittomma africana* (Lymexilidae) and (B) Larva of *Melittomma* sp. (From Scholtz and Holm 1985; reproduced by permission of University of Pretoria).

2.8. Platypodidae: Pin-hole Borers, Platypodid Ambrosia Beetles

2.8.1. Introduction

The terms "ambrosia beetle" and "pin-hole borer" apply to all Platypodidae, as well as many Scolytidae. Both families are sometimes considered subfamilies of the Curculionidae, but forest entomologists generally deal with them as separate families. Wood attacked by ambrosia beetles contains small circular tunnels surrounded by a dark fungal stain (Figure 5-24). At the time of attack, piles and/or cylinders of frass are ejected from the entrance holes (Plate 38). Although not structurally compromising the wood, the tunnels and stain normally result in timber degrade. In the long run, the initial attack by the beetles and their fungal associates also provides access for secondary wood rotting fungi.

2.8.2. Beetle/Fungus Relationships

Ambrosia beetles are fungivorous (xylo-mycetophagous) insects. For food they depend entirely on symbiotic "ambrosia" fungi that grow in the round, uniform tunnels built by the adult beetles in trees. Depending on the species of beetle, the tunnels penetrate the sap- or heartwood in different configurations and planes.

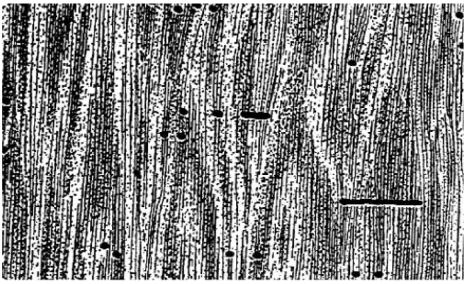


Figure 5-24. Dark-stained tunnels of uniform width characterize ambrosia beetle attack in wood. (From Curry 1958; reproduced by permission of Director, Kenya Agricultural Research Institute (KARI)).

All ambrosia beetles live in obligatory symbiosis with at least one symbiotic fungus (Batra 1985). Upon hatching, the beetles already carry the fungus in special body pouches (mycetangia or mycangia). When the beetles invade a tree, propagules overflow or slough off, inoculating the wooden walls of the galleries. Depending on the species, either the male, the female, or both carry the fungus. In addition to these primary ambrosia fungi, there may be non-specific auxiliary ambrosia fungi, many of which have sticky spores adapted for external transmission by various invertebrates associated with trees (Batra 1985). Most of these ophiostomatoid Fungi Imperfecti and yeasts (Schedl 1972b, Beaver 1989; Kinura 1995) are part of more or less fortuitous fungal successions, with the primary, obligate ambrosia fungi at the start. This assortment of fungi may include tree pathogens as well as pathogens of invertebrates. The typical dark stains surrounding ambrosia beetle galleries result from the cumulative action of both primary and auxiliary fungi.

2.8.3. Beetle/Host Relationships

The Platypodidae are a large family of predominantly tropical wood borers. Browne (1965) differentiated five categories of ambrosia beetle attacks on living trees in the tropics: (1) persistent attacks on apparently healthy trees, (2) sporadic mass attacks on apparently healthy trees, (3) attack on trees of temporarily reduced vigor, (4) attack through injuries, and (5) attack on very unhealthy or dying trees.

Only three species of tropical platypodids, none of them in East Africa, successfully attack healthy or near-healthy hosts (Schabel and Madoffe 2001). East African species are usually associated with moribund trees or recently cut logs (Gardner 1957a). The beetles may attack living trees, but typically are unsuccessful in establishing broods, as hosts, such as eucalypts and *Pterocarpus*, "sap" them with copious exudations of gum (Beaver 1976; Beaver and Löytttyniemi 1991). Such trees may recover from exploratory drilling by the beetles, and it is quite common to observe galleries deep in the wood of externally sound, freshly harvested trees (Gardner 1957b; Roberts 1978). African platypodids are generally polyphagous on many hardwoods. Only one West African species is considered monophagous.

Fungal requirements significantly affect host selection behavior of the beetles, the success of broods, and the prevalence of ambrosia beetles (Beaver 1977). Wood becomes unsuitable as soon as the moisture level of the sapwoods drops below 40% (Gardner 1957b). As a result, ambrosia beetles in East Africa are most common in warm, moist areas generally below 2,000 m.

2.8.4. Description

The elongate, yellow to dark brown adult platypodids are on average 2-12 mm long and about 2 mm wide. They are completely cylindrical in section, and their general outline is more or less rectangular with parallel sides (Figure 5-25) (Schedl 1972). To house the large anterior legs, the pronotum is emarginated at the sides. In most species, the elytra of males carry teeth on the hind margin. The short antennae are a single club, as opposed to two in lyctids and three in bostrichids. First instar larvae (Figure 5-26) are oval-trapezoid, flat and with lateral protuberances (Browne 1972). While they have only two pairs of spiracles, subsequent instars have nine pairs and are more typical cylindrical, nearly straight, legless grubs, with a slightly swollen middle portion and prothorax (Figure 5-27).

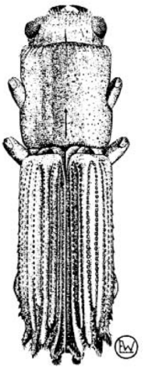


Figure 5-25. Triozastus banghaasi, a platypodid ambrosia beetle associated with legume trees. The rectangular shape of this beetle is characteristic for the Platypodidae. (From Schedl 1972).

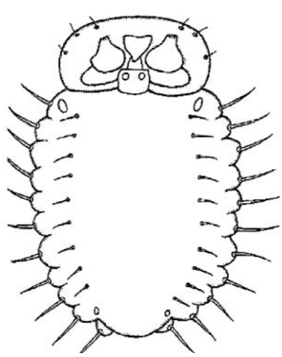


Figure 5-26. First instar larva of *Doliopygus* sp. (Platypodidae). (From Browne 1972b; reproduced by permission of The Royal Entomological Society of London).

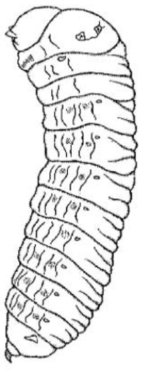


Figure 5-27. Last instar larva of *Trachyostus schaufussi* (Platypodidae). (From Browne 1972b; reproduced by permission of The Royal Entomological Society of London).

2.8.5. Life History

Platypodids do not differ greatly in their biology. In Zambia and Tanzania, the beetles are present throughout the year, but are most active during the first half of the rainy season (Löyttyniemi *et al.* 1985; Madoffe and Bakke 1995). Typically, the male finds

a host and digs a short, cylindrical tunnel. If his pheromone fails to attract a female, he will die there. After mating, the female takes over the tunnel and extends it, often extensively and deep into the heartwood, while the male ejects the frass and defends the entrance. All galleries are of uniform width and spread into two or more transverse planes connected by longitudinal tunnels. Eggs are laid in several batches, for a total of perhaps 100-200. The larvae develop in the tunnels, move around freely while grazing on fungus, and eventually pupate there or build a short pupation tunnel. Based on *Euplatypus* spp., there may be five instars (Schedl 1972a). The newly hatched adults also feed on ambrosia fungi before escaping through the original tunnel entrance. The beetles are monogamous.

2.8.6. Management

In areas where the major flight period of platypodids coincides with the rainy season, as is the case at Kimboza, Tanzania (Madoffe and Bakke 1995,1996) and in the Zambian miombo (Beaver and Löyttyniemi 1991), the dry season is recommended for cutting. Green logs of indigenous species can still be attacked most of the year, but at lesser intensity. Other control recommendations for ambrosia as well as bark beetles include hasty retrieval and processing of wood, sanitation, careful site-host matching, trap trees and pesticides. Common predators include Colydiidae and Cerylonidae (Col.), whose larvae are parasitic (Löttyniemi and Löyttyniemi 1988).

2.8.7. Major Platypodid Ambrosia Beetles of Tanzania

After Indo-Malaysia, Africa is the second richest area for platypodids in the world. *Trachyostus,* including a few species in Tanzania, are endemic to Africa and Madagascar (Schedl 1972b). One very widespread species, *Diapus quinquespinatus* Chap., was introduced to Africa from the Orient early and is now distributed from West to East Africa, Zaire and Zambia. This beetle is of potentially considerable economic importance as it tunnels deeply into the heartwood of recently felled, large diameter stems of many species (Beaver and Löyttyniemi 1985b). While Gardner (1957a) listed 41 species of platypodids in six genera for East Africa, at least 57 platypodid species were documented for Tanzania by 1970, compared to 45 in Kenya and 21 in Zambia (Schedl 1972a). In adjusting Schedl's figure for synonymies, the number of platypodid species recorded in Tanzania presently stands at 55 (RA Beaver, pers. comm.) This number will certainly be adjusted, as it recently was for Zambia, where at least 36 species of platypodids are now known to occur (Beaver and Löyttyniemi 1989, 1991). The numerous synonymies associated with platypodids were recently revised by Wood (1993).

Crossotarsus (=Platypus) externedentatus F. *(=C.* and *Trachyostus saundersi* Chap.*)*. This is one of the most widely distributed ambrosia beetles in the tropics, occurring from sub-Saharan Africa through most of tropical Asia as far East as Japan and Hawaii (Schedl 1972a). *C. externedentatus* attacks over 100 hosts, including small stems from as thin as 5 cm to larger logs (Booth et al. 1990). In Fiji alone, 69

tree species belonging to 42 plant families were attacked (Roberts 1978). The stained pinholes tend to be confined to about 10-15 cm of the timber core, usually resulting in heavy degrade (Booth et al. 1990). In most circumstances, the beetle will only select stressed or recently felled trees. Occasionally living, apparently healthy trees are also attacked, but the beetles are usually rejected by the flow of copious gum (Beaver 1976). Attacks on living mahoganies *(Swietenia macrophylla)* in otherwise promising plantations in Fiji and Samoa, proved only successful in stressed trees, while mahoganies growing in favorable conditions remained completely free of attack (Beaver 1976; Roberts 1978). Most mahoganies attacked were either edge trees, trees inside plantations where forest operations had taken place, or in storm-damaged plantations. Attacks were generally more pronounced at lower elevations and where drainage and soils were poor, i.e., on unfavorable sites. They usually started within 1-3 weeks of a disturbance and persisted for up to five months afterwards. This beetle has also attacked living eucalypts and other exotic plantation trees in parts of the South Pacific region (Beaver 2000).

The beetles (Figure 5-28) are 3.5-5 mm long (Booth et al. 1990). Their color is pale to reddish brown, except for the apical half of the elytra, which is slightly darker. The antennal funicle is 4-segmented, the scape asymmetrical and the club is strongly flattened. The elytra are finely dented and grooved and are mostly shiny except for the apical third being dull. The larvae are typical platypodid grubs (Gardner 1932). In Fiji, an average-sized brood consists of about 30 offspring, and in felled trees the life cycle of *C. externedentatus* takes about 50 days (Beaver 1976). At Kimboza, Tanzania, this beetle flew throughout the year (Madoffe and Bakke 1995). Species of *Crossotarsus* are characterized by a gallery system with the pupal cells arranged in candelabrum-shaped clusters at the ends of vertical galleries (Beeson 1961; Schedl 1972a).

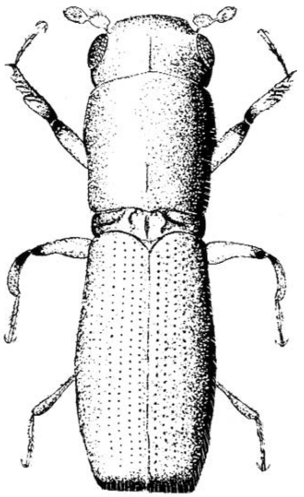


Figure 5-28. Crossotarsus externedentatus (Platypodidae). (From Booth et al. 1990; reproduced by permission of CABI Publishing).

In Fiji, wherever a conversion from natural forest to mahogany plantation had resulted in a rich reservoir of poison-girdled native trees, delaying planting by five years was initially recommended, but damage levels continued to be sufficiently serious to stop further extensive plantings (Beaver 1976, 2000). Avoidance of disturbance and sanitation are generally considered helpful (Mayhew and Newton 1998).

Doliopygus spp. Out of a total of 140 species (Figure 5-29) in this genus, over 26, and possibly as many as 50, occur in East Africa (RA Beaver, pers. comm.). This is thus the most species-rich genus of Platypodidae in this part of the world. Almost all

species attack moribund trees or recently felled logs. However, *Doliopygus dubius* (Sampson), a species widespread from Senegal to Botswana, occasionally attacks living trees and breeds successfully in them, without, however, killing the host (Beaver and Löyttyniemi 1985b). *D. dubius* attacks living *Terminalia superba*, as well as fresh logs in West Africa, where it is called the ofram borer (Wagner et al. 1991). In the miombo region, many species of *Doliopygus* attack legume trees, but this may simply be a function of the abundance of certain legumes in that forest type, as in different areas species of *Doliopygus* show variability in host preference (Beaver and Löyttyniemi 1985b). *D. exilis* Chap. and *D. serratus* Stroh., two species from Kimboza, are highly polyphagous and fly throughout the year (Madoffe and Bakke 1995).

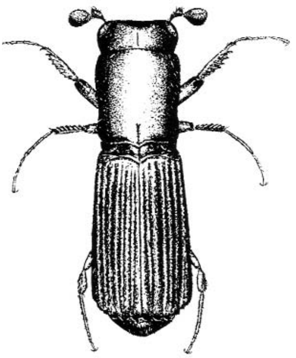


Figure 5-29. Doliopygus erichsoni, typical representative of the most species-rich genus of Platypodidae in East Africa. (From Booth et al. 1990; reproduced by permission of CABI Publishing).

Euplatypus Wood *(=Platypus)* spp. Relatively few representatives of this genus (Figure 5-30) are known from Tanzania and of these, little more than host and distributional records (Gardner 1957a; Curry 1958; Schedl 1972a). These species are 3-7 mm long, yellow- or red-brown to black beetles. Most are widespread and polyphagous (Schedl 1972a; Beaver and Löyttyniemi 1985b). *Euplatypus parallelus* (F.) (=*Platypus linearis* Steph.) occur not only in sub-Saharan Africa, but also from the southern USA to Argentina and are presently expanding in Indo-Malaysia (RA Beaver, pers. comm.) *Euplatypus (=Platypus) hintzi* (Schauf.) is also widely distributed in the Afrotropics and like *E. parallelus* occurs more commonly in secondary and managed forests and mill yards, than in primary forests. It is known to attack at least 195 hosts (Schedl 1972a) and flies throughout the year (Madoffe and Bakke 1995, 1996). While almost any species of moribund tree is selected, *E. hintzi* has on occasion heavily, but unsuccessfully, attacked living, seriously drought-stressed trees. Its gallery system is a branched tunnel in the transverse plane with pupal cells grouped above and below short tertiary branches (Booth et al. 1990).

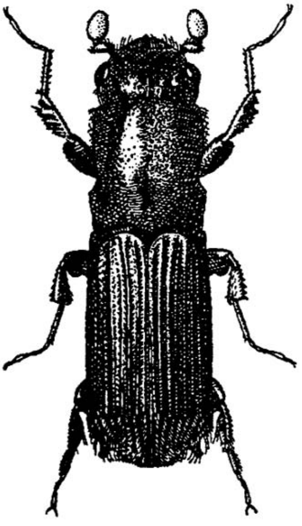


Figure 5-30. Euplatypus sp. (Platypodidae). (From Curry 1958; reproduced by permission of Director, Kenya Agricultural Research Institute (KARI)).

Chaetastus (=Symmerus) spp. Of these, *C. montanus* (Schedl) is common in the Kenya Highlands and in Tanzania in the Meru forests and West Usambara. This beetle attacks at least 22 hosts in 12 families, but seems to have a preference for *Olea* spp. (Gardner 1957a, c; Curry 1958; Gichora and Owuor 1990). It usually occurs in trees scorched by fire, in felled logs or in stumps, as well as standing dead and girdled trees. Living, fire-scorched trees are attacked but may recover. The inner wood of large and vigorous trees with perfectly sound outer wood have, on felling and conversion, been found to be heavily tunneled by these beetles. The galleries cross the grain of sap- and heartwood.

The related species, *C. tuberculatus* (Chap.), occurs commonly on many hosts from West to East Africa, and Zaire to Angola. Its attacks are restricted to moderate or larger stems. This species has also been recorded attacking living but unhealthy eucalypts and *Hevea* in Kenya and Ghana, respectively (Beaver and Löyttyniemi 1985b).

2.9. Scarabaeidae: Chafers, Lamellicorns; White Grubs

2.9.1. Oryctes spp.*: Rhinoceros Beetles*

Of the 38 species of rhinoceros beetles, several are major pests of various palms, especially coconut and oil palm throughout the warmer parts of the Old World (Bedford 1979; Lever 1979). *O. rhinoceros* is the most important coconut pest in the Asia and Pacific region, while three other species account for similar damage in parts of Africa. Their distributional records are somewhat inconsistent among authors (Morstatt 1914b; Lever 1979; Le Pelley 1959; Hill 1983), but according to Paul (1985), *O. monoceros* (Ol.) is distributed along the East African coast from Kenya to Mozambique, in the Seychelles, also in West Africa, some mountain areas of Inner Africa, in South Africa and the Yemen. In Tanzania it occurs not only along the coast but also on Zanzibar, Pemba and Mafia, as well as in the Usambara and Nguru Mts. *O. boas* (F.) is more widespread through much of tropical Africa, into Egypt, the Yemen, Madagascar and South Africa, including palm-free areas. *O. gigas (=cristatus)* Lap., much larger than the previous two, is up to 72 mm long and occurs from Senegal to the Congo, East Africa to Madagascar (Möbius 1898; Morstatt 1912c). It is recorded as rare in Tanzania (Morstatt 1911c; Paul 1985). Of the three, *O. monoceros* is the most serious pest (Paul 1985). *O. monoceros* and *O. boas* were considered a serious menace to the coconut industry in German East Africa (Morstatt 1911c) and on Pemba and Zanzibar (Mansfield-Aders 1919/20), as they are to this day on these islands and along the coast of Tanzania. In some plantations more than half of the young palms are killed by the beetles, while others are stunted.

2.9.2. Impact

Damage by *Oryctes* results from one or rarely 2-3 of the large beetles boring into the terminal bud spear at the top of mostly 1-4 year old, but up to 8 year old, healthy

palms, to feed on the sap (Vosseler 1905b). Beetles initiate this attack (Plate 39) 1-3 hours after dark with preference for isolated palms or those along borders. They feed on average for nine days, making tunnels averaging 46 cm, but up to two meters long (Paul 1985). Masses of fibrous extrusions near the entrance tunnel (Figure 5-31A) are early signs of attack. As a result of this invasion, parts of sometimes more than four of the developing leaves are destroyed. This becomes evident in characteristic v-shaped notches of the expanding fronds (Figure 5-31B) or drooping tips (Plate 40). A single beetle can kill a young palm if its tunnel penetrates the palm heart, i.e., the growing point. The simultaneous attack by several beetles can also kill a palm, because water accumulates in the abandoned tunnel. This causes a strongly odorous bud rot (Morstatt 1911c). Leaves on the upwind side are the first to die. Following storm damage or drought, when breeding places abound, even older trees may be killed (Paul 1985).

Figure 5-31. External signs of attack by the coconut rhinoceros beetle *Oryctes monoceros* (Scarabaeidae). (A) Fibrous extrusions from the entrance tunnel. (B) Typical v-notches in fronds of coconut. March, Zanzibar Island.

2.9.3. Description and Life History

In Tanzania, all stages can be found throughout the year although the egg stage peaks in the rainy season (Paul 1985). The complete cycle from egg to adult takes on average about half a year (Lever 1979). In Tanzania it takes only about 12 weeks

for *O. monoceros*, and slightly longer for *O. boas* (Paul 1985). Females lay approximately 25-50 white-yellowish, oval, 3.5-6 mm long eggs, which hatch in about 7-12 days. Larvae take 2-6 months to develop in three instars. Bedford (1979) describes the third instar larva of *O. monoceros* and provides a key to the larvae of the three species of *Oryctes* in East Africa. A mature larva (Figure 5-32A) is a 6-8 cm long, c-shaped, white grub with three pairs of thoracic legs. The immature stage feeds harmlessly on a wide range of moist, organic material, but *O. monoceros* prefers rotting palm trunks, especially the soft, shaded upper and mid portions of standing or downed palms. Pupae are as plump as the grubs and are encased in hard pupal chambers consisting of surrounding organic materials and frass. After about 2-3 weeks, they hatch into 32-48 mm long adults that remain in their cells for several weeks. These beetles are shiny brown in *O. boas* and dull brown in *O. monoceros* (Peringuey 1901-02; Morstatt 1911c). Males sport a rhinoceros-like frontal horn that is about 1 cm long in *O. boas* (Figure 5-32B) but shorter in *O. monoceros*. Females of *O. monoceros* exhibit a small horn, while those of *O. boas* have only a minor projection. The beetles are night-active, strong fliers and capable of attacking many palms during their 3-4 months of adult life. During this time they alternate feeding periods with mating (Paul 1985).

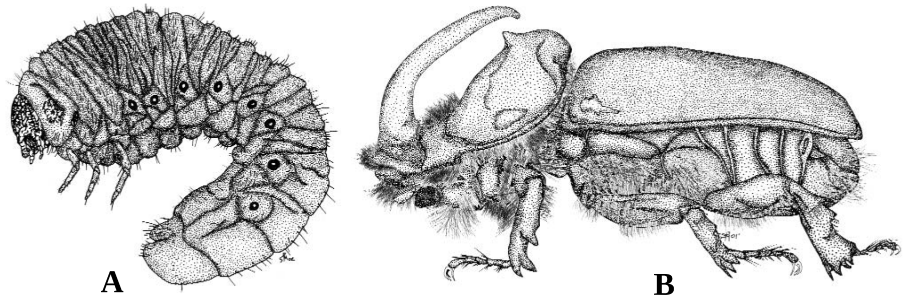


Figure 5-32. Oryctes boas (Scarabaeidae). (A) Advanced larva. (B) Male beetle. (P. Schroud).

2.9.4. Management

Because during colonial days the Germans attached great significance to a vibrant coconut industry, they vigorously promoted this particular crop (Schabel 1990). In the process of expanding coconut plantations, they tried to deal with the persistent rhinoceros beetle problem by offering cash incentives for the collection of these pests (Vosseler 1905b, 1907h; Morstatt 1911c, 1914b). This proved a very popular source of income for the locals, leading to a collecting frenzy. In Dar es Salaam almost 30,000 grubs were delivered in a few days and one young collector supposedly garnered a month's worth of wages in one day (Vosseler 1905b). This approach ultimately proved too expensive and not sufficiently effective. Sanitation, i.e., the removal and burning of dead trunks and piles of moist, rotting plant and animal matter, the breeding materials for the larvae, was substituted and led to greater success

(Vosseler 1905b; Morstatt 1911c). In conjunction with a new coconut development program begun in the 1980s, a more integrated control effort evolved, emphasizing a combination of physical, biological and cultural methods (Schabel 1983; Paul 1985). At the heart of this integrated strategy is the initial reliance on existing natural controls and the routine establishment of ground cover as well as dense cultures of coconut. This is based on the fact that bare plantations and isolated trees are more subject to attack, while vegetative barriers interfere with the flight of beetles. For smaller-scale operations, two hands full of coarse sand applied to the leaf axils of young palms may be a labor-intensive but effective method to deter the beetles (Vosseler 1905b; Morstatt 1911c). The spearing ("winkling") or extraction of beetles from their tunnels with a 75 cm long, barbed harpoon (Plate 41) can also be effective, if done repeatedly while populations are low. Active tunnels are easily identified by the sound made by the beetles. Where damage levels are excessive, additional measures are employed. The emphasis is first and foremost on sanitation, especially at sites with an abundance of breeding material. Fresh trunks can be disposed of by utilization or they can be cut into sections, loosely piled and later burned or used as bait logs. Sanitation can be combined with traps of moist sawdust or rich organic material, which are searched for specimens at three-month intervals (Morstatt 1914b). Some success with biological control of rhinoceros beetles in the Pacific Islands, employing a baculovirus and a fungus (*Metarhizium anisopliae major*), prompted similar attempts in Tanzania (Paul 1985). Unfortunately, the Pacific strain of the virus, obtained from *O. rhinoceros*, was not sufficiently virulent against *O. monoceros*, and the fungus, which occurs naturally in Tanzania, was not investigated in sufficient depth to allow a final judgment on its feasibility. The same fungus had already been found earlier in Zanzibar and other strains were imported for experiments that did apparently not proceed for unknown circumstances (Mansfield-Aders 1920). In certain islands in the Indian and Pacific Oceans, rigorous control utilizing several of above principles, actually succeeded in exterminating rhinoceros beetles (Lever 1979).

There are numerous other, non-specific natural enemies of *Oryctes* including another fungus (*Cordyceps*), *Oecophylla* red ants and the shrike (Plate 42). Mansfield-Aders (1920) mentioned shrews, elephant shrews and crows. The beetles frequently carry numerous phoretic mites and pseudo-scorpions that prey on these mites (Vosseler 1905b).

2.10. Scolytidae: Bark Beetles, Engraver Beetles or Scolytid Ambrosia Beetles

This family of about 6,000 species worldwide is richly represented in Africa (Schedl 1939, 1957, 1959, 1959-1962, 1972a,b). Scolytids are closely related to the platypodids and the combined literature on both is voluminous (Wood and Bright 1987). However, while all platypodids and most African scolytids are xylo-mycetophagous ambrosia beetles that depend on symbiotic wood fungi for food, some scolytids are phloeophagous bark beetles feeding on sub-cortical tissues in trunks, branches, shoots or roots. Still others are spermatophagous specialists destroying fruits or seeds.

In the temperate and subtropical zones, certain bark beetles belong among the most troublesome tree killers of conifers and hardwoods. In the tropics, however, most scolytids are generally more serious as ambrosia beetles that degrade timbers with pin-holes and stains (Beaver and Löyttyniemi 1985a), or as notorious pests of cash crops such as coffee, tea, and cocoa. Overall, platypodids in Africa are more abundant and harmful than are Scolytidae, while in the temperate zone the reverse is true.

Present evidence concerning scolytids in living trees in tropical Africa generally indicates stressed hosts; however, occasionally healthy seedlings and saplings have been killed by normally twig-boring species (Schabel and Madoffe 2001). *Hylastes angustatus* (Herbst), one of several exotic bark beetles established in pine plantations from southern Africa up to Zambia, has caused problems because adult beetles feed on the young, green bark of the root collars of seedlings in newly established stands (Tribe 1991). As of 2000, this beetle had not spread beyond southern Africa. As is also true for platypodids (Roberts 1978), forestry operations such as thinning, pruning, transplanting, cleaning and tree poisoning prior to harvest or for weed tree removal, often trigger or contribute to temporary, sometimes spectacular local build-ups of these beetles (Roberts 1978; Curry 1965a). To prevent epidemics, stress avoidance in hosts and sanitation measures are recommended.

2.10.1. Description

Scolytids are generally in the 0.5-13 mm range. They are mostly cylindrical, yellow, brown or black beetles, often shiny and sparsely haired, but sometimes dull or covered with setae or scales (Figure 5-33A). The short, elbowed antennae end with an abrupt 3-segmented club. Scolytids and platypodids differ based on the length of the first tarsal segment in relation to the remaining segments (Wood 1993). In the scolytids, seg-

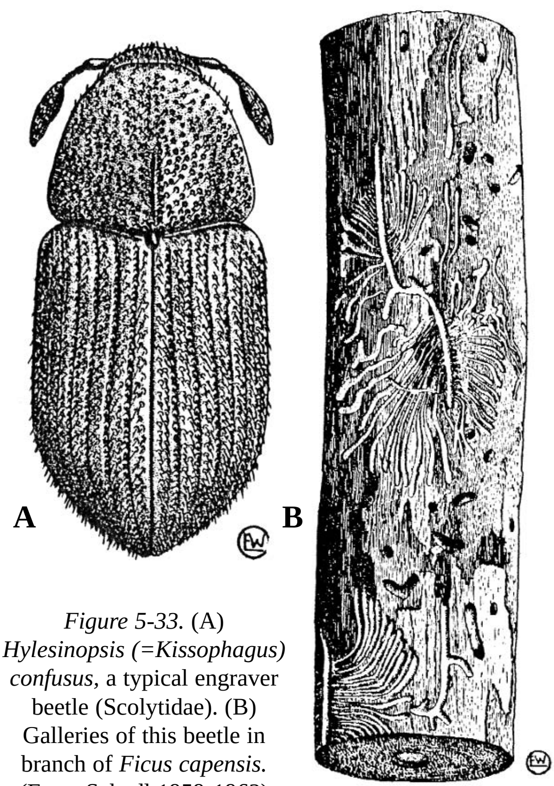


Figure 5-33. (A) *Hylesinopsis (=Kissophagus) confusus*, a typical engraver beetle (Scolytidae). (B) Galleries of this beetle in branch of *Ficus capensis*. (From Schedl 1959-1962).

ments 1-3 are subequal in length, while in the platypodids segment 1 is usually about as long as segments 2-5 combined. The larvae of scolytids are legless, cyclindrical and c-shaped, virtually identical with those of the weevils.

2.10.2. Life History

Knowledge of the biology of African scolytids is very limited, but it can be assumed that it is similar to that of relatives elsewhere. Typically, the adults of bark and engraver beetles dig into the subcortical zone of stressed trees or green logs where they establish a single gallery, or, if polygamous, several egg galleries of uniform width. After the larvae hatch in egg niches carved along the tunnels, they start building their own, gradually enlarging, frass-filled tunnels. Rather than placing eggs into individual egg niches, a few species lay their eggs loose or clumped together, and the larvae develop side by side in a gradually enlarging communal tunnel. The overall pattern of adult and larval galleries together is very characteristic for the genus or species (Figure 5-33B), allowing identification even in the absence of the insects (Schedl 1959b). Many of these beetles are at least fairly host-specific and frequently vector ophiostomatoid, free-living fungi which cause, or at least hasten, host mortality. This group of scolytids subsists mainly on bark or young sapwood, but may also eat some of the auxiliary fungi associated with them in as yet poorly understood relationships (Batra 1985).

Over half of tropical scolytids and the majority of African scolytids are xylomycetophagous pin-hole borers, i.e., larvae and adults subsist on specific, symbiotic "ambrosia" fungi, which grow in tunnels in the sap- and heartwood, much in the pattern described in conjunction with platypodids. Built by the adult beetles, the tunnels are round, of uniform width and clear of frass, their walls coated with mats of fungal mycelium. Like platypodids, the scolytid ambrosia beetles are often highly polyphagous. Many species prefer hosts of certain sizes, and only successfully attack recently cut timber or stressed hosts compromised by difficult site conditions, diseases, drought, fire and other injuries (Beaver 1977). Host immunity is rare (RA Beaver, pers. comm.)

The flight intensity of scolytids is most pronounced at the onset of rains and continues through the rainy season (Löyttyniemi et al. 1984; Madoffe and Bakke 1995). At an altitude of about 1,000 m in the East Usambaras, the beetles started flying at about 9 am and peaked in the afternoon (Strohmeyer 1911). As host material desiccates during extended droughts, the growth of ambrosia fungi either arrests or slows down. As a result, the dry season flight of some species is reduced, while other seasonal species apparently aestivate in litter (Beaver and Löyttyniemi 1985a; Madoffe and Bakke 1995). Depending on location and circumstances, some development may, however, take place during the cold/dry period, and overlapping generations are likely in some species.

2.10.3. Major Scolytids of Tanzania

Gardner (1957a) listed only 62 species of scolytids for East Africa, but there are likely many more. For Zambia, 59 species of scolytids were reported in the 1980s, 36 for the first time, indicating that any focused search for these beetles is likely to considerably expand existing lists (Beaver and Löyttyniemi 1985a). Ten of the species recorded were circumtropical, 28 afrotropical, 13 East African and 8 endemic.

Phloeosinus bicolor (Brulle) *(=P. schumensis* Egg.*)* Since German days this bark beetle has occasionally attracted attention for the simple reason that its hosts include valuable conifers, i.e., native *Juniperus procera* (Figure 5-34) as well as exotic *Cupressus benthami* and *C. lusitanica* in the highlands of East Africa (Gieseler 1906; Gardner 1957a). This beetle commonly attacks freshly killed logs, as well as declining, suppressed, and sporadically, also weakened trees. Especially trees compromised by drought and growing on poor sites, as well as cypresses damaged by rats appear susceptible (Gardner et al. 1953; Jones 1967). However, since the egg galleries of this beetle are restricted to the phloem, the damage is minimal. By judging from European experience with bark beetles, Gieseler (1906), mistakenly identifying this beetle as *Hylesinus* sp., was of the opinion that it had the potential to kill healthy trees in mass outbreaks, a sentiment shared by Curry (1965a). Claims of *P. bicolor* attacking apparently healthy cypress plantations in Kenya (Gichora and Owuor 1990), are however, not sufficiently substantiated to be taken as evidence for this scenario. The flagging of twigs on healthy trees, which is commonly observed (Peake 1949), probably results from maturation feeding of adult beetles on tender bark and is apparently inconsequential, unless leading shoots are affected.

Figure 5-34. Freshly cut logs of *Juniperus procera* as in a historic picture from the Usambara Mts. are often attacked by the scolytid ambrosia beetle *Phloeosinus bicolor.* (From Pflanzer 1912, Beiheft No. 1).

Xyleborus spp. This was the largest genus of scolytids worldwide with hundreds of species of ambrosia beetles exclusively associated with woody hosts (Beeson 1961), until a recent revision by Wood (1993) split it into a number of smaller genera. In East Africa alone, 24 species were recorded (Gardner 1957a; Le Pelley 1959) and in West Africa 40 (Wagner et al. 1991). These beetles typically attack dying twigs and branches, but a few are associated with larger logs and some occasionally with living trees. A few species select fruits.

Beetles in the genus (Figure 5-35) are from straw- to brick-colored or black, cylindrical to hemispherical or globular, and range from 1-8 mm long (Beeson 1961; Curry 1958). Only females are involved in attacks on trees, and no attractant pheromones seem to be involved. The few males, produced from unfertilized eggs, are frail, short-lived beetles with reduced eyes and greatly reduced hind wings (RA Beaver, pers. comm.) They do not bore tunnels and do not leave the galleries in which they mate with their sisters. Many species are size-selective but highly polyphagous, attacking trees in many unrelated families. Oligophagous representatives tend to select botanically related trees.

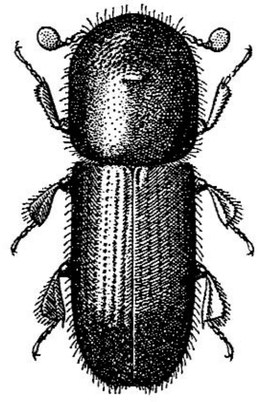


Figure 5-35. Xyleborus sp., representing the largest genus of scolytid ambrosia beetles (Scolytidae). (From Curry 1958; reproduced by permission of Director, Kenya Agricultural Research Institute (KARI)).

Xyleborus beetles are often very abundant. In one study in Zambia, they accounted for 87% of scolytids caught (Löyttyniemi et al. 1984). At Kimboza, three species of *Xyleborus* were reported flying throughout the year (Madoffe and Bakke 1995, 1996). Their economic importance is, however, generally slight, except in some woody crops such as cocoa, coconut, coffee, rubber and several fruit trees. With the exception of rubber and cocoa trees, hosts need to be compromised by severe stress before being attacked. In natural forests, the beetles are merely among a number of other pin-hole borers that attack green timber. Their damage is limited, as tunnels rarely penetrate deeply into the wood. Serious damage results only when they attack living trees through bark injuries (Browne 1962), and relatively few species may attack and kill live, young trees.

Xyleborus ferrugineus F. is the best-known species in this genus. It is listed by 16 scientific names, the name *X. confusus* Eich. appropriately being the most common synonym for Africa (Browne 1962). This is a near cosmopolitan species with a wide distribution in parts of the USA, tropical America, the Pacific region and Australia, as well as tropical Africa and Madagascar (Browne 1962). It is associated with over 200 tree species worldwide including pine logs, agricultural trees and healthy cocoa trees (Beaver and Löyttyniemi 1985b). This beetle usually occurs at altitudes below 1,500m. In East Africa, it was documented on *Afzelia, Albizia, Antiaris, Avicennia, Khaya*

and *Maesopsis* (Gardner 1957a; Austarå 1969). It usually infests dying and dead trees, as well as newly felled timber with or without bark, preferring moderate to large-sized material. Living trees may be attacked through bark wounds. The nest is a system of irregularly branched tunnels lying for the most part in one transverse plane of the wood which the beetle penetrates to a depth of little more than 50 mm. As with other species of *Xyleborus*, only the females fly. They are attracted to light, usually on dry days during the earlier hours of darkness. Beetles are believed to aestivate in the forest litter. The length of the life cycle likely varies in different parts of this beetle's vast range.

Several other species of *Xyleborus* also range extensively. The cosmopolitan *X. affinis* Eich. *(=X. mascarensis* Eich.*)*, a 2.2-2.3 mm long beetle, is polyphagous and not size-selective on over 300 hosts including hardwoods, palms and a few conifers. In West Africa, it is reported to have a preference for Meliaceae and Sterculiaceae, and to have girdled and killed many transplanted saplings in a number of hosts (Browne 1961). It is also an occasionally important pest in agricultural trees and a common degrader of wood (Beaver and Löyttyniemi 1985b). It is extremely abundant in Zambia (Löyttyniemi et al. 1984).

Xyleborus morstatti Hag. (now *Xylosandrus compactus* (Eich.)), is a 1.4-1.9 mm long dwarf occurring from West Africa to Fiji. It attacks over 225 species of trees in 62 families including conifers (RA Beaver, pers. comm.). It usually attacks seedlings, shoots and small twigs through an entrance hole of about 1 mm diameter (Browne 1961). A circular brood gallery of about 8 mm length with short branches running up or down accommodates a brood of 10-50, depending on area. In different parts of the world, different ambrosia fungi are associated with the galleries of this beetle, and there may be more than one species of fungus in one host (Browne 1961). On the Ivory Coast, this beetle is a major pest of "robusta" coffee and to a lesser extent cacao, avocado, coca and cola (Brader 1962). In Indonesia, it is implicated as a borer in living twigs and branches of mahogany leading to wilt and breakage (Mayhew and Newton 1998). In India, it killed seedlings and saplings of *Khaya* spp. (Meshram et al. 1993) and in Malaysia there was one instance of serious injury in a forest nursery (Browne 1961). In the Ivory Coast, females produce an average of 16 offspring and development takes about 28-43 days from egg to adult including three larval instars.

*Xyleborus bidentatus (*Motsch.*)* *(=Xyleborus (=Progenius) riehli* Eich.*)* reaches from coastal forests in East Africa to Sulawesi. Its gallery system (Figure 5-36) is simply bifurcate or trifurcate in a transverse plane and often very crowded, with 1.5 entrance holes to the square centimeter (Browne 1961).

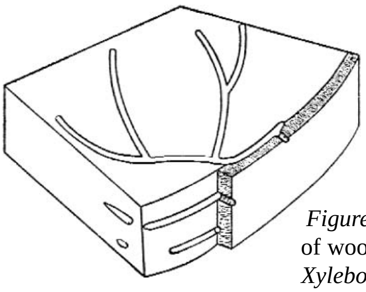


Figure 5-36. Section of wood with nests of *Xyleborus bidentatus.* (From Browne 1961).

Xyleborus perforans (Woll.) (=*X. testaceus* Wlk.*; =X. kraatzi* Eich.), a 2.1-2.5 mm long beetle, is an almost cosmopolitan in the humid tropics, attacking over 100 species of hardwoods, conifers and palms in forests as well as in open country, even sugarcane. This is the most common pin-hole borer in southern Asia, where it may have originated, and a dominant species extending into the adjoining tropics. Its occurrence in East African mangroves probably results from the habit of traveling as a stowaway in exported timber. It is not size-selective and may attack living trees through injuries or diseased patches of bark, but more often targets moribund trees, green logs or newly sawn timber (Browne 1961). By tunneling 8-10 cm deep, it causes considerable damage in sawn, unseasoned timber. The nest tunnel, in one transverse plane, has numerous irregular branches, but no brood chambers (Figure 5-37) (Browne 1961). In sugar cane, its lifecycle takes three weeks, but 4-6 weeks may be more normal in wood (RA Beaver, pers. comm.)

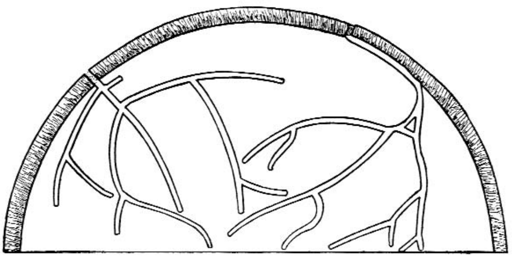


Figure 5-37. Transverse section of log with nests of *Xyleborus perforans.* (From Browne 1961).

Xyleborus volvulus (F.) is another circumtropical pest of numerous trees. In Zambia it even occurs in pine stumps (Beaver and Löyttyniemi 1985b).

2.10.4. Miscellaneous Other Scolytids

A few other scolytids have been observed in conjunction with conifers in East Africa (Gardner 1957a). They include *Lanurgus podocarpi* Schedl., which attacks logs and sickly, drought-stressed *Podocarpus,* and *Hypothenemus setosus* (Eich.) (=*Stephanoderes congonus* Hag.) in dead shoots of living *Pinus patula.* The pantropical ambrosia beetle *Hypothenemus eruditus* Westw. is occasionally found in fire-killed cypress. In West Africa, where the life cycle of this minute beetle takes 3-5 weeks, it is known to attack unhealthy seedlings and twigs of several hardwoods (Wagner et al. 1991).

3. HYMENOPTEROUS BORERS

Carpenter bees (Xylocopidae) and wood wasps (Siricidae) are of interest to African forestry, but only the former occur in East Africa at this time. Two species of wood wasps (*Afrotremex* spp.) are indigenous to South Africa, and *Sirex noctilio* F., a native of Europe and North Africa and a serious pest in Australia, New Zealand and South America, was discovered there in 1994. It has since spread North and East, is presently established in the provinces of Western Cape, Eastern Cape and KwaZulu Natal, making it the most important pest of pines in South Africa. It is expected to move into the remaining pine-growing areas of South Africa and into Zimbabwe

(B Hurley, pers. comm.). Annual releases of the nematode *Beddingia siricidicola* may eventually contain this pest in Africa, as it has elsewhere.

3.1. Xylocopidae: Carpenter Bees

More than 700 species of large carpenter bees occur throughout the warmer regions of the world. Taxonomists disagree on whether to include these bees with the family Apidae or Anthophoridae, or to treat them as a separate family, the Xylocopidae.

3.1.1. Impact

There are at least 24 *Xylocopa* spp. in East Africa (Morstatt 1912d; Le Pelley 1959). Some of the most common, such as *X. caffra* L. are widespread. Carpenter bees are useful pollinators. They can, however, also be a nuisance as they heavily attack exposed wooden structures, particularly the projecting ends of rafters and beams, making them unsafe (Gardner 1957b; Jones et al. 1966). In East Africa, they prefer podo timbers as well as cedar fence posts (Peake 1949). Under natural conditions, their circular tunnels, slightly more than 10 mm across and 15-17.5 cm long, are built in the dry, smooth-textured wood of dead branches or trees (Plate 43). Nests are almost always, more or less extensively, branched. Some carpenter bees nest in abandoned tunnels. Several related, smaller bees, including leaf cutter bees (Megachilidae), also like to nest in abandoned tunnels or build their own tunnels in dry, rotten wood, and thus are not primary borers in sound wood. Carpenter bees make only a living in wood, i.e., without consuming it. They eject most of the excavated fibers, only using some for the construction of cell partitions. Only after considerable provocation is their sting put to use. It is said to not be very painful.

3.1.2. Description

The adult bees are 20-30 mm long, stocky, densely pubescent, mostly black insects with bands of yellow or white (Figure 5-38). Unlike bumble bees, the back of their abdomen is smooth and glossy. As there are no bumble bees in sub-Saharan Africa, the only insects that could be mistaken for carpenter bees are certain robber flies (Asilidae: *Hyperechia* spp.). These Diptera are in both looks and size uncanny mimics of carpenter bees, and thus are described below.

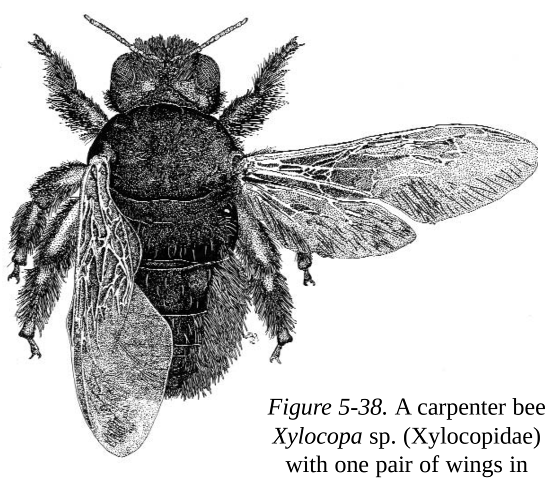


Figure 5-38. A carpenter bee *Xylocopa* sp. (Xylocopidae) with one pair of wings in resting position. (P. Schroud).

3.1.3. Life History

Although little research concerning the biology of carpenter bees has been done in East Africa, their behavior is well-known from studies in southern Africa (Skaife 1953; Watmough 1974).

Carpenter bees are solitary bees with certain social tendencies, i.e., they clean their nests and the young bees may be fed to some extent. Females probably mate only once (in flight) with a polygamous male, and hibernate as mated adults. The ratio of males to females is 1:2. In the spring, when the wood is dry and there is abundant flowering, female bees find a sheltered location to construct a tunnel. They collect pollen mostly from legumes and Labiatae, mix it with nectar and then deposit this paste ("bee bread") at the end of her tunnel to serve as food for a larva. After laying one large, white, curved egg on top of this larder, they seal off this cell with a spirally-built cross wall made of a mix of sawdust and saliva. The bees then proceed to provision a string of additional cells until most of the tunnel is filled. Six to seven cells amount to about a month's work. In dry years the fecundity of females, usually less than 10, is even lower (Watmough 1991). As unguarded nests are often robbed by ants or by other carpenter bees, the female rarely leaves for food. The eggs hatch about two weeks after being laid and the larvae take 3-4 weeks to pupate. After hatching, the young carpenter bees break down the partitions and continue to live in the tunnel as a family, leaving occasionally to feed. A tunnel may contain all four stages at the same time, although the adults are segregated from eggs, larvae and pupae by still existing cross walls. With spring arriving, the bees become more active and the males are driven out to find communal bachelor tunnels to live in. Males can often be observed hovering for lengthy periods of time in search of females. As the females left behind become mutually aggressive, more and more are driven off until only one remains in the original tunnel. In South Africa, there is only one generation of carpenter bees a year and the greater part of their comparatively long life of about a year is spent in the adult state. Other species, especially in the more tropical parts of Africa, are likely to have several generations a year.

3.1.4. Management

Control of carpenter bees as structural pests can be achieved with contact pesticides, or preventatively by whitewashing or painting the wood to be protected (Gardner 1957b; Jones et al. 1966).

Natural controls include rain, which limits reproductive activity and increases mortality, as well as a number of more or less specialized predators and parasitic wasps (Watmough 1974). *Pheidole* ants often harass the bees sufficiently to force them to abscond. Certain mites, living in body pockets on female bees, either feed on bee bread or may be directly parasitic. Woodpeckers, baboons, squirrels and rats play a highly important role in the regeneration of carpenter bees, by feeding on the bee bread, or eggs, larvae and pupae, frequently destroying over 90% of nests. Most intriguing, however, are certain robber flies and blister beetles, whose biology is intricately connected to that of the bees.

Three of the 13 African *Hyperechia* spp. (Dip: Asilidae) occur in East Africa (Hull 1962; Oldroyd 1974). In size (22-35 mm long) and appearance, these robber flies exhibit striking mimicry of carpenter bees (Figure 5-39). This close resemblance has fooled many an observer, especially since the flies tend to frequent the neighborhood of carpenter bee nests. Eggs of the robber flies are laid in crevices on the surface of wood near the bee's tunnel entrance. From there, the larvae have easy access to the nests where they parasitize several bee grubs, often moving from one tunnel to another (Lamborn 1927). Pupation occurs in a cavity dug outside the xylocopid tunnel from which the mature pupa wiggles its way to the entrance of the tunnel to hatch (Figure 5-40). As adult *Hyperechia* are predators of various smaller Hymenoptera, and they are themselves parasitized by an encyrtid wasp, an intriguing scenario of predation, parasitism and hyperparasitism involving a number of insects emerges.

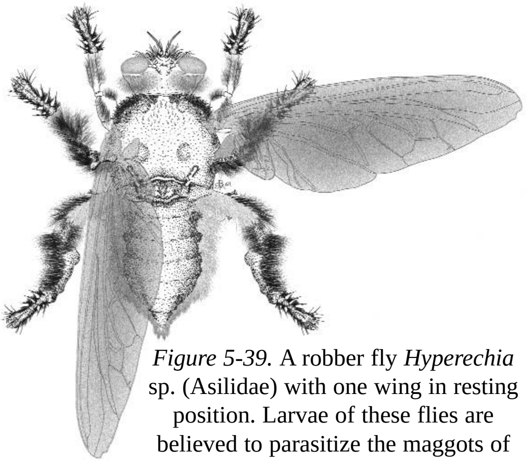


Figure 5-39. A robber fly *Hyperechia* sp. (Asilidae) with one wing in resting position. Larvae of these flies are believed to parasitize the maggots of carpenter bees, while the adult flies are mimics of carpenter bees and prey on various Hymenoptera. (P. Schroud).

Figure 5-40. Hatched pupal shell of *Hyperechia* sp. (Asilidae) sticking from a carpenter bee tunnel in a sideboard.

Both in the Old and the New World, some species of blister beetles (Col.: Meloidae) are routinely found in the nests of carpenter bees and their larvae hitch rides on the bees. Little is known about their biology (Clausen 1976; Bologna and Laurenzi 1994). The first instar larvae, called triungulins, are parasitoids of Apoidea and are phoretic on them, but the exact nature of parasitism involved is still unclear. Several species of carpenter bee blister beetles (*Synhoria* spp.) are known from East Africa. These are about 22-35 mm long, brick red beetles with black legs and antennae. They have patchy distribution, but are commonly seen around wood stocks where carpenter bees abound (Esbjerg 1976). Despite their size and the formidable mandibles, the males (Figure

5-41) are harmless and apparently do not feed. According to Watmough (1974), the eggs are laid on or near *Xylocopia* nests. Up to 30 first instar larvae (triungulins) have been found clinging to hairs of adult bees that transfer them to newly laid eggs in still open cells. The larvae of the blister beetle puncture and kill an egg after which they transform into fat larvae that feed on bee bread. For pupation, each larva bores a cell into the end of the bee's tunnel, breaking through intervening cells and devouring any bee larvae and pupae on the way. The adult beetles live for about a month. Males attract females by extending their head and thorax out of a bee tunnel. Le Pelley (1959) reported *Cissites fischeri* Kolbe as occurring in nests of *Xylocopa* sp. in Kenya, but as this genus is restricted to the Americas, he likely referred to *Synhoria* sp.

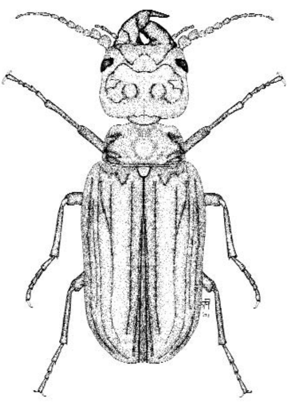


Figure 5-41. Male *Synhoria* sp. (Meloidae). First instar larvae of this large beetle are phoretic on adult carpenter bees, while older larvae prey on eggs and larvae of carpenter bees, and compete for their food. (P. Schroud).

4. LEPIDOPTEROUS BORERS

While the vast majority of Lepidoptera are defoliators, there are also wood, root and shoot borers. With few exceptions, very little detail concerning representatives in these categories exist at this time. As a result, only two families will be briefly dealt with here.

4.1. Cossidae: Carpenterworms; Goat Moths

The caterpillars of this family are wood borers in many parts of the world. Carpenterworms tunnel extensively in branches and trunks (sometimes roots) of living trees over one year old. Their activity only becomes evident after flux oozes on the outside bark, frass is ejected from the galleries and hosts wilt, die back or are killed entirely. This family includes the bee hole borer, *Xyleutes ceramica* Wlk., the worst enemy of teak in Asia. Although widely distributed in Africa, most cossids are scarce there and very poorly known (Clench 1959). The subfamily Cossinae is surprisingly species-rich in Africa, but is in a highly disorganized state, with generic assignments often doubtful and no higher attempt at classification evident.

4.1.1. Description and Life History

Goat moths are medium-sized to large, heavy-bodied moths, often attracted to light. They tend to be mottled brown-grey-white. The moths lay a total of some 1,500 eggs, typically into bark crevices or holes in the wood. The young caterpillars first feed on

the outer bark (Plate 72) then bore into the wood where their development may take up to two years. Pupation occurs just below the surface of the bark. Eventually the pupa breaks through the remaining bark and, with rows of spines on the abdominal segments, wiggles halfway to the exterior for the moth to hatch.

4.1.2. Eulophonotus (=Engyophlebus) myrmeleon Feld.*: Cocoa Stem Borer*
This borer occurs from West to East Africa. Its reputation as a pest is largely based on its impact on cocoa in West Africa (Hill 1983), but in East Africa it tunnels in branches, trunks and sometimes roots of *Combretum* and *Populus* over one year old, causing dieback (Gardner 1957a). Male moths are 20-28 mm across the almost clear wings, while the females have a 45-50 mm spread, and both pairs of wings are sooty brown with many small, clear patches. Each female lays about 1,500 eggs which incubate for about two weeks. Larvae need at least 12 weeks to develop and the pupa stage lasts about three weeks.

4.1.3. Salagena discata
Recently, this East African native, sometimes classified as belonging to the family Metarbelidae, caused massive deaths of natural stands of the mangrove *Sonneratia alba* along the Kenyan coast (Mwangi 2002). Before burrowing into the wood of branches, the larva notches away a patch of bark about 5-8 cm across. Parts of the muddy brown frass are ejected from the gallery. Several caterpillars may occupy one branch, which often dies back. Recurrent infestation of all branches causes tree death. What triggered the sudden outbreak of this borer remains unclear. In parts of India, *Indarbela quadrinotata* is considered a key pest of *Casuarina*, and in Zambia, a species of *Salagena* near *tessellata* had previously damaged pole-sized *Eucalyptus tereticornis* by chewing patches of bark (Selander and Bubala 1983).

4.1.4. Azygophleps and Xyleutes spp.
The most common species of cossids in East Africa are in the closely related genera *Azygophleps* and *Xyleutes*. The former attack *Cassia siamea* (Le Pelley1959) and *Hagenia abyssinica* (Gardner 1957a), but little more seems to be known about them. Of the species of *Xyleutes*, one is fairly notorious and thus somewhat better known, although less for detail, than for impact.

*Xyleutes capensis (*Wlk.*): Castor Stem Borer, Thorn Tree Borer*. The caterpillars of this moth, which occurs from East to South Africa, routinely attack *Cassia* spp., resulting in wilt, dieback and death of trees. In a trial plantation of *C. siamea* in Tanzania, 50% of the trees were attacked (Gardner 1957a). Another attempt to grow the same species in Machakos, Kenya was essentially foiled, when after eight years 100% of the trees exhibited shoot dieback, and 80% showed signs of attack by *X. capensis* (Speight 1996). Stress apparently played a role in this attack, as trees pruned for fodder production were significantly more infested than others. The larvae (Plate

44) are huge, dirty white in color, and have four rows of round, brown spots along the body (Skaife 1979). The caterpillars presumably live for 1-2 years (Hill 1983). Relatives of *X. capensis* include *Xyleutes vosseleri* and *X. sjöstedti* Aur. (Figure 5-42A, B), but nothing seems to be known about their biology. *X. vosseleri* adults are about 35 mm long and have a wingspan of 70-100 mm (Hill 1983).

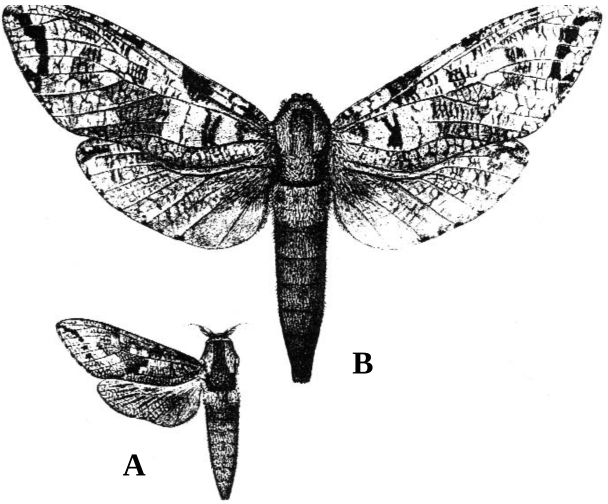


Figure 5-42. (A) Male and (B) female carpenter moth *Xyleutes sjöstedti* (Cossidae). (From Sjöstedt 1910).

4.1.5. Miscellaneous Other Goat Moths

The larva of a large but unidentified cossid was observed boring just beneath the bark of kapok, constructing tunnels of frass and silk on the surface, and injuring the trees by ring-barking the branches (Harris 1938). *Coryphodema tristis,* a south African cossid, recently caused extensive damage in eucalypts in that country.

4.2. Pyralidae: Shoot-boring Caterpillars; Snout moths

This is a large family of about 20,000 species of delicate, small to medium-sized, dull brown or grey moths with thread-like antennae, long narrow wings and long, slender legs. The caterpillars of pyralids are slender, nearly naked, and drab, having little if any color pattern. Their habits are variable, but many live as borers in various plant parts, especially shoots, fruits and stored products. When disturbed in their silken tubes, they wiggle out of reach. Pyralids are common pests in different crops throughout the world. Few are listed for East Africa. *Polygrammodes hirsutalis* Wlk., which occurs on *Ficus* in Tanzania, may be insignificant (Le Pelley1959). The greater and lesser wax moths are also members of this family and are mentioned in chapter 9 in conjunction with apiculture.

4.2.1. Hypsipyla robusta (Moore): *Mahogany Shoot and Fruit Borer*

Hypsipyla shoot borers, sometimes classified as belonging to the family Phycitidae, are widespread in the tropics and constitute the main obstacle in the culture of mahoganies, i.e., Meliaceae, Swietenioideae. *H. robusta* has been long considered an Old World species occurring throughout West and East Africa, India, Southeast Asia,

Indonesia, Australia and a few of the Pacific islands (Beeson 1961, Roberts 1968). However, recent evidence from Australia and Southeast Asia suggests, that this is not one, but at least seven different species with the status of the different populations still unresolved (Horak 2001). The closely related *H. grandella* (Zell.), on the other hand, now considered four species, ranges throughout the Neotropics from South Florida, through many Caribbean islands and Central America into South America, except Chile (Mayhew and Newton 1998). Together, *Hypsipyla* spp. account for many complete plantation failures of mahoganies (*Swietenia* spp.), and are an impediment to the culture of other valuable Meliaceae, including *Carapa*, *Cedrela*, *Chukrasia*, *Entandrophragma*, *Khaya* and *Lovoa*. In Nigeria, *Khaya* spp. suffered much heavier attack than other hosts, and certain mahoganies are hosts in some areas, but not in others (Roberts 1968). In Tanzania, considerable shoot damage in nursery plants and saplings of *Khaya* was attributed to *H. albipartalis* Hamps. (Gardner 1957a).

H. robusta attacks flowers and fruits, bark and shoots, with regional differences in host and in host part preference which are likely attributable to different *Hypsipyla* spp. On inflorescences, single larvae (Nigeria) or groups (India) make a loose web and feed within, usually spending the day in a silken tunnel. Rare fruit attacks in high rainfall regions of India only involve species with small fruits, such as *Carapa* and *Cedrela* (Beeson 1961). In Nigeria, however, attacks on fruits of *Carapa*, *Entandrophragma* and *Khaya* spp. are only observed in the rain forest zone (Roberts 1968). Fruits attacked show a hole with accumulations of red frass, silk and gum, and may fall prematurely. Fruits of *Khaya* often contain several larvae, and those of *Carapa procera* in Nigeria have yielded up to 26 caterpillars each (Roberts 1968).

Damage to the bark of trees by groups of larvae is apparently restricted to East and West Africa, as it has not been reported elsewhere. In Africa, the phloem of all species of *Khaya* is attacked. Signs include frass and heavy exudations of gum which solidify in curled tendrils on the trunks. Successful breeding in bark seems to be rare, however, as dead larvae are frequently found drowned in this gum.

Most pernicious throughout their range is damage to the shoots of mahoganies (Figure 5-43). Each larva may attack several shoots by moving from one to another, but it takes only one larva to kill a terminal and thus disfigure a tree. The attack is most pronounced on newly produced tissues and may persist throughout the life of the tree. Shoots on trees as young as three months old and less than 1 m high may already be attacked, but 3-6 year-old trees in the 2-8 m range are most susceptible (Beeson 1961). Evidence of attack at first includes frass and silk at the tip of the shoot, then drooping of neighboring leaves and finally death of the shoot. Infested trees rarely die, but destruction of terminal buds and shoots results in serious growth reduction and the forking of trunks (Figure 5-43) renders them unmarketable as lumber.

Together with their taxonomy, the biology and ecology of *Hypsipyla* spp. are still poorly understood (Griffiths 2001b). In Ghana, females lay from 11-65 (avg. 50)

eggs (Atuahene and Souto 1983). These are white or mottled with red and white patches. They are laid directly on the very young shoots, fruits, bark and flowers. After 3-5 days, the larvae hatch. Depending on which part of the host is attacked, caterpillars either bore into the tissues or build silken shelters. They vary from pale straw through brown, pink, green to blue with a series of black warts arranged in five longitudinal rows on each side of the body, the spots of the first and third rows being larger. In advanced instars, the newly molted larvae often grade from reddish-brown, to pinkish, purple or reddish-blue and finally to greenish or bright blue, the characteristic color of the 19-29 mm long mature caterpillar. There seem to be regional differences in the life cycle of *H. robusta* in that four instars have been reported from India and Nigeria, as opposed to 5-6 for Ghana and the Ivory Coast (Atuahene and Souto1983). Pupae are from 10.5-15.7 mm long and come in various shades of light to darker brown. They are typically found within fruits or shoots or on surrounding structures, beneath loose bark, or on the ground. In India, larvae attacking fruits and flowers spin to the ground and pupate on low vegetation. The moth is pale rufous brown, mixed with gray and black, and sexes are similar. The forewings have pronounced black veins and are crossed with zigzag black lines and patches, while the hind wings are whitish and semi-translucent except for the anterior region which is dark.

Figure 5-43. Multiple leaders on a seedling of *Khaya ivorensis,* resulting from the mahogany shoot borer *Hypsipyla* sp. (Pyralidae). (Reproduced by permission of P Bosu, For Res Inst Ghana).

The wingspread is 20-32 mm in males and 23-42 mm in females (Beeson 1961, Atuahene and Souto 1983). Moths resulting from bark-fed caterpillars are, however, smaller than shoot-fed ones (Roberts 1968). The sex ratio is 1: 1 and moths are nocturnal (Atuahene and Souto 1983).

The biology of *H. robusta* as reported by Beeson (1961), Roberts (1968) and Atuahene and Souto (1983) reveals a number of similarities, but also some differences, as already pointed out. Certain intrinsic species differences, but also climate and preference for a specific host part, seem to account for most of the divergences. In India's temperate and subtropical regions there are fewer generations per year and different parts of the tree are attacked by different generations. In more tropical areas, generations are more numerous, and they feed almost entirely in the shoots of the food plants. Females, which are strong fliers, lay 200-450 eggs over 5-8 nights (Griffiths 2001a). The total life cycle of *H. robusta* takes anywhere from 3-8 weeks, excluding diapause (Griffiths 2001a). Bark-feeding caterpillars in Africa generally take about two more weeks than those feeding on shoots. Assuming a life cycle, egg to adult, of about five weeks at lbadan, Nigeria, Roberts (1968) allowed for possibly ten generations a year in high forest areas of that country where young shoots are available the year round. As flowers and fruits are only available temporarily, only one or two generations of caterpillars can be expected to affect these parts, respectively. Young larvae were absent during the dry season in savanna areas of Nigeria at which time mature larvae apparently aestivated as was also reported for drier parts of India. Pupation occurs in host stems, or in soil and debris (Griffiths 2001a). The pupal period. in tropical India takes about 10 days and moths emerge there throughout the year.

Many biological, chemical and silvicultural methods have failed to reduce damage to economically acceptable levels (Mayhew and Newton 1998). A number of parasites have been listed for *H. robusta* in West Africa, but only the nematode *Hexamermis* sp. was sufficiently abundant on older, shoot-boring larvae in the early part of the rainy season to achieve a degree of control (Roberts 1968; Atuahene and Souto 1968). Studies with neem against *H. grandella* suggested that azadirachtin may prevent some early stage shoot borer larvae from attacking shoots of mahoganies (Howard 1995; Mancebo et al. 2002). However, results of a recent trial in Florida, were less promising. The lack of a method to predict shoot borer attacks with sufficient precision to allow timely application of preventative measures continues to be the major impediment to products such as azadirachtin (FW Howard, pers. comm.). In spite of a great deal of research with chemical pesticides, no chemical control product has effectively and consistently provided economic control of these pests (Speight and Wylie 2001). Evidence for silvicultural control of *Hypsipyla* is, unfortunately, conflicting and to a great extent anecdotal (Mayhem and Newton 1998). In natural regeneration, the incidence of *Hypsipyla* tends to be very low or negligible under shelter of older trees (Beeson 1961), and where both nurse crop and mahogany are planted in the same area, apparently some degree of control has been obtained (Roberts 1968). Pure stands of Meliaceae, with all trees planted very densely is also said to give a measure of control (Roberts 1968). As wild stocks of mahoganies have been gravely depleted and their commercial extinction is predicted for the near future, new attempts are now being made in West Africa and elsewhere, to get on top of the vexing problem of shoot borer attack through an integrated pest management strategy (Opuni-Frimpong and Cobbinah 2000; Atuahene 2001; Floyd and Hauxwell 2001).

CHAPTER 6

ANTS AND TERMITES

1. INTRODUCTION

While the preceding three chapters were organized according to insect activity (defoliating, sap-feeding and boring), this chapter deviates from this pattern for reasons that become evident by looking at similarities between the two groups.

1.1. Similarities

The general public often pools ants and termites by calling the latter “white ants” and their mounds “ant hills”. Although entomologically incorrect, a number of uncanny similarities may underlie the confusion. Both are social insects of similar size and abundance, and both are polymorphic, i.e., their colonies are composed of castes which perform different functions. Both become similarly agitated and belligerent when disturbed, and they inhabit similar places, i.e., underground nests, wood, arboreal nests or mounds. Although less obvious, both share an odd trait; at least one of the reproductive castes sheds both sets of wings at the end of the nuptial flight and continues life as a wingless adult. Given their overall biomass, it is not surprising that both occupy significant ecosystem niches, ants almost globally, termites in the warmer zones. They also share a number of enemies. Ants number among the worst antagonists of termites and of other ants. In addition, certain termites and ants cultivate fungi, although no fungus-cultivating ants are known from Tanzania. Last not least, both termites and ants include species suitable for human food.

1.2. Differences

Despite these similarities, a number of important differences exist (Table 6-1). First, ants and termites represent two entirely different orders. Termites belong to the primitive Isoptera and thus have three stages of development (incomplete metamorphosis), while ants belong to the more advanced Hymenoptera with four stages (complete metamorphosis). While all Isoptera are termites, not all Hymenoptera are ants. In both, the fertile females are long-lived. However, while termite kings cohabit with

Table 6-1. Major differences between ants and termites.

	Ants (Hymenoptera)	*Termites (Isoptera)*
Metamorphosis	4 stages	3 stages
Longevity of Fertile Males	Short-lived	Long-lived
Workers	Females only	Both sexes
Integument (color)	Mostly sclerotized (dark)	Mostly unsclerotized (light)
Antennae	Elbowed	Straight, thread- or beadlike
Front and hind wings	Dissimilar size	Equal size
Cerci	Absent	Present
Waistline	Constricted	Broad
Food habits	Variable	Cellulose-based
Distribution	Cosmopolitan	Warm climates

the queen for years, the fertile male ant dies shortly after mating. Ants have only female workers, whereas termite workers may be of either sex.

Aside from the color (termites are mainly light-colored and ants darker), more subtle morphological differences include the antennae, the relative size of front and hind wings and their type of venation, as well as the presence or absence of a pair of small abdominal appendages (cerci). In the termites thorax and abdomen are broadly jointed, as opposed to the constricted waistline of ants. Ants and termites also differ in food habits and distribution.

1.3. Significance in Forestry

From a forestry point of view, it is not easy to collectively classify either ants or termites as pests, or as beneficial and useful insects. Some species tend to be one or the other, while many others combine negative with positive aspects. In ecological terms, both termites and ants are mostly beneficial. However, a small fraction of termite species in the four families occurring in East Africa kill young trees, damage older ones and destroy wooden structures. In parts of the world, some species of ants are of concern as defoliators, girdlers or wood destroyers. Of the four families of ants of special interest to Tanzanian forestry, two include predators, mostly of termites. The other two include predaceous species that protect trees against browsers, defoliators, borers and termites, while at the same time tending honeydew-producing aphids and other sap-feeding insects, to the detriment of the same trees.

2. ANTS (HYMENOPTERA: FORMICIDAE)

2.1. General

The total number of recorded ant species worldwide numbers almost 12,000, but actual numbers probably exceed 20,000 species. At this time, 1,686 species have

been described from the Afrotropics (H Robertson, pers. comm.). A recent study at Mkomazi in Tanzania, one of the best-collected sites for ants in Africa, revealed 232 species, at least one third undescribed (Robertson 1999, 2002).

2.1.1. Castes

Mature ants are characterized by large heads, elbowed antennae, and constrictions of the second, or second and third abdominal segments forming a distinct waist. Typically a colony consists of one queen and a set of wingless, sterile female workers that tend a brood of eggs, and the maggot-like larvae and pupae (naked or contained in cocoons, depending on species) kept in chambers. In some species, workers called minors and majors differ in size. The majors of certain species have modified heads that help them function as soldiers. Some ants are blind, while others see very well. Only kings and virgin queens are winged for the duration of their nuptial flight. Mating takes place on the wing, the male dying shortly afterwards. The queen sheds her wings to retreat to a nest, where she remains producing eggs fertilized by stored sperm, possibly for years.

2.1.2. Habits

Some ant species form small colonies, while other colonies number in the millions. Based on where ants nest and forage, Robertson (1999) differentiated four groups, i.e., arboreal, ground-dwelling, litter species and subterranean ants. With the exception of a few nomadic ants, all live in permanent structures. Their nests occupy existing, or excavated hollows in soil or wood. Some build arboreal carton nests or leaf nests, others inhabit termitaria, and some occupy preformed structures (domatia or myrmecodia) on certain plants. Symbiotic relationships exist not only with such “ant plants”, but also with numerous species of invertebrate ant affiliates (myrmecophiles) (Kohl 1909; Hölldobler and Wilson 1990; Kistner 1998). Most prominent among these are various rove beetles, ant nest beetles and lycaenid caterpillars that live in ant nests as detritus feeders, parasites or predators. They often mimic ant brood or the ants themselves, morphologically and/or chemically. Many other free-living insects and spiders are also morphological ant mimics. Other symbiotic relationships exist with many small Homoptera such as aphids, scale insects and hoppers. Ants tend and defend these insects like cows and may even build stables for them. In return they milk them for honeydew. Occasionally, when a herd becomes too big, they may even slaughter some of their “cows”.

2.1.3. Significance

In terms of distribution, diversity of social systems, ecological adaptations and numbers, ants are the most successful of social insects (Hölldobler and Wilson 1990). Their biomass, especially in certain tropical forests, exceeds that of all vertebrates combined by several factors. Ants’ impact on trees often involves beneficial as well as noxious elements. On the plus side, ants may be important seed distributors (myrmecochory) and soil modifiers. Many are carnivores and thus reduce populations

of tree defoliators and other pests, especially termites (Way and Khoo 1992). Arboreal ants also discourage browsers by defending their hosts with fierce stings, bites and repulsive or irritating substances. On the other hand, the same ants may kill tree shoots and buds. Trees also suffer direct growth impact from the sap-feeding Homoptera associated with them, or indirectly from the action of secondary agents. For instance, honeydew supports sooty mold fungi that may interfere with leaves' photosynthesis and gas exchange. Many Homoptera are also known to be vectors of virus and phytoplasma diseases. Ants themselves are important links in food chains. Their worst enemies are other ants although there are also numerous predaceous vertebrates, including ant specialists.

2.1.4. Classification

Given the large number of ants, it is convenient to deal with subfamilies. Out of 16 worldwide, 11 occur in Africa (Bolton 1994). Four subfamilies include species with noxious, beneficial or otherwise useful representatives of greater interest to forestry in Tanzania. Two of the four subfamilies discussed (Dorylinae and Ponerinae) are entirely carnivorous. The dorylines occur in huge, nomadic colonies, the ponerines in smaller, more stable colonies. The two other subfamilies, Myrmicinae and Formicinae, feature more diverse characteristics and include beneficial and damaging species. Pupae of the myrmicines have no cocoons, the petiole of adults appears two-segmented and the workers carry stings, while most formicines have pupal cocoons, their petiole appears to be one-segmented and their workers have no stings, but spray ant acid (formic acid) instead.

2.2. Dorylinae: Driver, Safari or Legionary Ants, Siafu, Sausageflies

Dorylus (=Anomma) spp. These nomadic, carnivorous ants are found from the Sahara to the Cape and through tropical Asia (Skaife 1953). Only this one genus of Dorylinae, which includes two subgenera with different habits but a similar appearance, is represented in the Afrotropics. Species in the subgenus *Anomma* are partly subterranean and vicious, while those in the subgenus *Dorylus* are entirely subterranean and timid (Silow 1983). Two species, *D. helvolus* L. and *D. nigricans* Ill., were listed for Tanzania (LePelley 1959), but *A. molestus* Gerst. appears to be the main surface-dwelling species in this country (H Robertson, pers. comm.). *D. helvolus* is less common and mainly subterranean.

2.2.1. Description and Life History

As detailed information concerning *D. molestus* in Tanzania is missing, the related *Anomma nigricans* and *D. helvolus*, as described by Forel (1911) and Skaife (1953, 1979), respectively, may serve as a guide. Driver ants undergo a four-stage metamorphosis. Their maggots (Figure 6-1B) are typical for ants and their pupae are naked. Colonies of driver ants consist of major and minor workers, soldiers and reproductives. The reddish-brown and completely blind workers (Figure 6-1C) are polymorphic,

i.e., there may be four types, ranging from midgets less than 2 mm long, to individuals of about 8 mm length. Soldiers (Figure 6-1D) are much larger than workers. They sport massively developed armored heads with huge sickle-shaped mandibles. Depending on species, the dark reddish-brown, blind and wingless queens (Figure 6-1E), considered specialized workers, are 29-51 mm long, making them the largest of all ants (Forel 1911; Hölldobler and Wilson 1990). As their abdomen is distended with eggs produced at the rate of 1-4 million per month, queens walk with difficulty only. Male driver ants (Figure 6-1F) are up to 30 mm long, medium brown insects with a fluffy head and thorax. They have wingspans of up to 44 mm and are the only seeing and winged form of siafu. On account of their large, sausage-shaped abdomen they are known as "sausageflies".

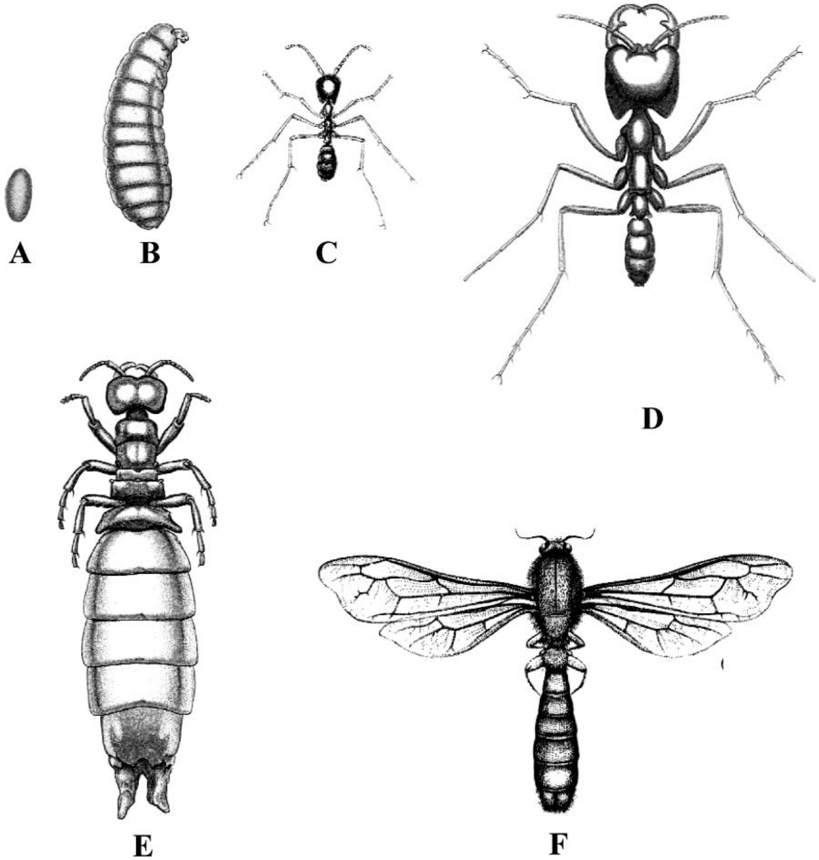


Figure 6-1. Driver ant *Anomma nigricans* (Dorylinae). (A) Egg (B) larva (C) worker (D) soldier (E) female (F) male. (A-E from Forel 1911/12; F from Pinhey 1974).

The degree of social organization by driver ants is only rivaled by that of certain bees and termites. However, the size of their colonies, with as many as 22 million workers (Hölldobler and Wilson 1990), sets them apart from those of other social insects. Much of the year, driver ants remain underground in often deeply (1-4 m) excavated bivouacs and only emerge with the rains (Skaife 1953). During that time, males depart for their nuptial flight and are frequently observed buzzing around lights. When caught, they ponderously mimic stinging motions. Despite this threatening demeanor, they are harmless impostors without a sting and even their sharp jaws are not used for biting. For mating, the males are captured and de-winged by workers before being carried underground to the queen.

Every 20-30 days, when food resources for several miles around the nest have been depleted, the whole colony moves in orderly fashion from temporary bivouacs deep below the surface at the base of a buried stone or tree stump, to seek new hunting grounds. The young and the queen are carried with them. A move is somewhat predictable, because 1-2 days before the exodus, myrmecophile rove beetles that live in the nest, appear in numbers at the mouth of the nest (Vosseler 1905c). The sheer number of driver ants, together with their reputation as “incomparably bloodthirsty” carnivores, compelled by “haste, chase, fight and slaughter” (Vosseler 1905c), invite sensationalization. A recent documentary by National Geographic highlighted and inevitably glamorized the world’s three most dangerous “Killer Ants”, including South America’s army ants (*Eciton* spp.), the Tasmanian bulldog ants (*Myrmecia* sp.) and Africa’s driver ants. Footage featuring the driver ants was filmed at Mt. Meru in Tanzania. The former two ant species sting viciously and the bulldog ant carries the most powerful venom of any insect. Based on the extraordinarily powerful mandibles of driver ant soldiers, however, the film declared siafu THE most dangerous, in fact Africa’s “top predators” and “the baddest little brutes on the planet”.

Driver ants are in fact able to overpower most forms of life that cannot get away from them. On dull days or at night, the leaderless swarms of many thousands of individuals raid in 12 m wide fronts accompanied by an ominous rustle. The moving hordes attack everything in their path and leave as suddenly as they come. Prey is cut up, transported to the nest and consumed there. They are generally considered a threat to confined domestic animals, sleeping children, and are rumored to have killed people such as the sick and drunks. In the early 1900s, siafu supposedly killed a leopard near Tanga (Vosseler 1905c). Pregnant Dorobo women are said to avoid stepping over siafu raiding parties for fear of abortion (Schnee 1920).

Despite their vicious image, these much maligned, feared and hated creatures are credited with being overall more beneficial than damaging. Vosseler (1905c) actually considered them a “blessing for tropical nature”, for the simple reason that most of their prey is composed of insects including termites and many crop pests. Also, just like certain soldier termites, siafu soldiers have traditionally been used in folk medicine to suture wounds, by forcing the gaping mandibles of soldiers to clamp shut at half a centimeter apart along a cut, before severing the bodies from the heads

(Silow 1983). After healing, the heads or stitches are removed. For the Ngindo of Tanzania, roasted and powdered driver ants served as starvation food in times of need (Silow 1983).

As an interesting tidbit of natural history, driver ants are associated with their own house flies (*Stomoxys ochrosoma* Speiser). These muscids are observed hovering over a column of driver ants, selecting worker ants without booty, then dropping a clutch of about 20 eggs on them. This egg bomb is carried into the bivouac where the maggots hatch to live as scavengers (Vosseler 1905c; O'Toole and Preston-Mafham 1985).

2.2.2. Management.

Given the overall beneficial role of driver ants, control is not likely to be needed except in the neighborhood of settlements and camps. Whenever they approach human habitation, siafu columns can be diverted with strips of wood ash (Morstatt 1910a). If a colony sets up a bivouac too close for comfort, a mix of soap with petroleum poured into the exits will discourage them. The Shambaa supposedly employ a specialist ("mganga ya siafu") to ward off ants that invade houses during the rainy season (Silow 1983).

The most important natural enemy of driver ants, as well as other ants and termites, is the pangolin (*Manis temincki*) (Vosseler 1905c), but this animal has become rare (Figure 6-2; Plate 45).

Figure 6-2. A pangolin *(Manis temincki)* rolled into a defensive ball. This is a specialized predator of ants and termites. Usangu.

2.3. Ponerinae

Pachycondyla analis (Latr.) *(=Megaponera foetens* F.*)*. Matabele ants are relatively large, subterranean ants occurring from West to South Africa (Skaife 1953). They are aggressive predators with a painful sting. Their food consists almost exclusively of the larger species of termites (Morstatt 1922; Le Page 1981; Weidner 1988; Nyamasyo 1989). In the Matumbi Hills of Rufiji District, the average predation rate of a colony of Matabele ants was 932 termites per nest per day (Bayliss and Fielding 2002). Since there were an average of 1,475 worker ants per colony and a total of 74,144 nests were estimated on the 4,634 ha large Namakutwa-Nyamuete Forest Reserve, the number of termites taken there in August/September amounted to 69×10^6 daily. Given the nest density of 16/ha in this coastal forest, as opposed to only 3.8/ha in a study in Kajiado, Kenya (Le Page 1981), these ants are obviously a major restraint on termites in Rufiji District. Since they nest mostly at the base of large trees, they are assumed to afford a high degree of protection for these trees from termites, at least temporarily.

Matabele ants raid as well-organized small armies of major and minor workers marching in columns 5-10 abreast to invade termitaria. In the Kenya study, there were three daily hunting peaks and each colony utilized 2,000-2,300 m^2 each year (Le Page 1981). They attack and sting termites in their nests, drag them maimed and dying to the outside, then dive in for more attacks. After each worker has secured 5-6 termites, they reassemble at the surface and carry off their prey to the nest.

The larger workers are up to 17 mm long and dull black with fine yellow hairs; the smaller ones are about 10 mm long and shinier (Sweeney 1976). The queen, about 20 mm long, looks much like a major worker but with a stouter abdomen. Pupae are contained in cocoons. Nests are underground, the entrances a simple hole without mound. Colonies move occasionally (Plate 73).

Other ponerine ants are specialized predators of various arthropods and earthworms in parts of Africa and Tanzania (LePelley 1959; Hölldobler and Wilson 1990; Robertson 1999). Most notable for East Africa are the African stink ants *Pachycondyla (=Paltothyreus) tarsata* and *P. berthoudi*, both also predators of termites.

2.4. Formicinae

2.4.1. Oecophylla longinoda (Latreille): *African Weaver, Tailor, Red Tree, or Majimoto Ants*

These ants are considered among the most successful social insects in the Old World tropics (Lever 1979). *O. longinoda* occur across most of the forested Afrotropics, while the closely related *O. smaragdina* F. range from India to Australia and the Solomon Islands. Because of their aggressive behavior and conspicuous communal leaf nests they are familiar to everyone working around trees in these areas.

O. longinoda is the dominant arboreal species of ant in the canopies of many soft-leaved species of wild and cultivated trees in tropical Africa. In Tanzania, they occur at altitudes up to 1,200 m and are particularly common in riverine forests (Vanderplank 1960).

More conspicuous than the ants themselves are their leaf nests (Plate 74). One colony builds hundreds of these in several trees, usually in the sunnier part of the peripheral canopy. Individual nests are connected by odor trails laid with secretions from a rectal gland (Hölldobler and Wilson 1990). Each leaf nest, about a foot or more across, incorporates living host leaves tied together by silk into tight compartments. Their construction requires the cooperation of ant workers as stitchers with last instar larvae who act as the silk factory. The workers hold the larvae in their mandibles and use them as animate shuttles to spin together the edges of leaves held in place by other workers (Vanderplank 1960). The leaves selected often harbor aphids and scale insects. Some nests may also contain myrmecophile lycaenid caterpillars that feed on the Homoptera with impunity.

Weaver ant colonies can be sizeable. The total population of only part of a small colony of 192 leaf nests assessed in Zanzibar was estimated to be between 115,000 and 164,000 individuals (Vanderplank 1960). More recent evidence suggests that in many colonies the worker force may exceed half a million (Hölldobler and Wilson 1990). A colony may exist for as long as five years (Vanderplank 1960). Workers defending the colony are usually housed in peripheral barracks. Neighboring colonies are separated by unoccupied corridors ("no ant's land"), but when encounters with other ants, including their own species occur, weaver ants behave most aggressively by emitting alarm pheromones from a mandibular gland, facing the intruder with gaping mandibles and cocking their abdomen to spray acid from a modified sting gland. Their Swahili name majimoto (hot water) ants, derives from the sharp pain associated with their fierce bite.

The caste system of majimoto ants consists of males and three forms of adult females: an apparently single queen, major workers that forage for food and perform a variety of other tasks, and minor workers that care for the eggs and younger nymphs (Hölldobler and Wilson 1990). Males and females usually live in separate leaf nests.

The bulk of a colony consists of major and minor workers, usually reddish-brown, leggy individuals with a pyriform head, long and strong mandibles and long antennae (Figure 6-3). In Tanzania, some colonies consist of yellow individuals with a high proportion of small workers to large ones, while others are composed of mostly large, dark workers (Vanderplank 1960). The former tend various Homoptera and are not aggressive, while the latter do not appear to tend Homoptera and are extremely aggressive. Major workers are 7-11 mm long.

Workers see very well and employ no fewer than five recruitment systems comprised of differing chemical and tactile signals, to organize territorial defense, foraging

excursions and the exploration of new terrain (Hölldobler and Wilson 1990). Majors also function as stitchers and will carry minor workers to locations where their work is required. Minor workers attend scale insects to collect honeydew and regurgitate it to major workers, who transport it into the brood nest for final consumption. Workers live for 68-140 days.

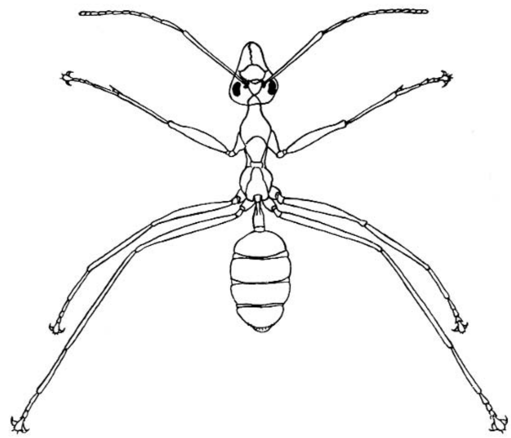


Figure 6-3. The arboreal majimoto ant, *Oecophylla longinoda* (Formicinae). (From Schmutterer 1969; reproduced by permission of Elsevier GmbH, Jena).

As researched in Tanzania, one queen may produce up to 930 eggs a day (Vanderplank 1960). To lay her eggs, she moves from nest to nest accompanied by a mob of protective workers acting as soldiers. Depending on temperature, the eggs incubate for about 1-2 weeks. The maggot-like larvae develop in 9-25 days, while the naked pupae take 3-12 days. The total period from egg to adult amounts to 18-50 days. After heavy rains, from November to May, winged females escape from their nests, preceded by males by days or weeks.

Weaver ants can be a nuisance for people around trees and their encouragement of sap-sucking Homoptera may have negative implications for host trees. However, they compensate to a great extent for this indirect damage by preying on a wide range of pest insects, especially termites, both on the ground and in tree crowns (Hölldobler and Wilson 1990). They even subdue large insects such as rhinoceros beetles (*Oryctes*) (Figure 6-4).

Figure 6-4. Majimoto ants, *Oecophylla longinoda* (Formicinae), subduing a rhinoceros beetle *(Oryctes monoceros).*

Based on this predatory habit, *O. smaragdina* is believed to have been the first insect employed for biological control of other insects more than 1,700 years ago in southern China (Hölldobler and Wilson 1990). Unfortunately, attempts to exploit *O. longinoda* in similar fashion for the biological control of palm pests in Tanzania, such as the fruit-spotting bugs *Amblypelta* and *Pseudotheraptus wayi* Brown (Coreidae), were considered, perhaps prematurely, a failure (Brown 1955; Vanderplank 1958, 1960; Way and Khoo 1992). Interference from several antagonistic species of ants constitutes a major complication in the management of *Oecophylla* ants (Way 1951, 1984). Most important among these are *Pheidole* (Myrmicinae) and *Anoplolepis* ants (Formicinae), because they depress weaver ants while allowing the pest coreids mentioned above to thrive and become damaging to palm crops.

Control of weaver ants is only justified, where they are too much of a nuisance (Lever 1979). To encourage the ants and reduce damage by *P. wayi*, the intercropping of citrus trees with coconut has been suggested (Behrens et al. 1993).

2.4.2. Other Formicin Ants

Many *Camponotus* spp. occur worldwide, including carpenter ants, a group of structural pests. In Tanzania only certain arboreal species with a craving for honeydew were mentioned as potential pests by LePelley (1959), as they favor the buildup of sap-feeding Homoptera.

2.5 Myrmicinae

2.5.1. Crematogaster spp.*: Black Cocktail Ants*

There are many species of black cocktail ants worldwide. Most are arboreal insects living under bark, in stipules, hollow branches or in conspicuous carton nests of variable size attached to tree branches. As with many other ants, their activities include both beneficial and noxious aspects. Many prey on termites, naked caterpillars and grubs and thus keep the host free of these insects. At the same time, these ants are fond of honeydew and thus frequently favor the buildup of scale insects and aphids to damaging levels. Most conspicuous and interesting are cocktail ants that build carton nests in trees and others inhabiting domatia in stipules, hollow branches or stems of various host plants (Kohl 1909; Hölldobler and Wilson 1990). Pupae and maggots make excellent bird bait (Silow1983) and the ants themselves have been used to clean small skulls for museum purposes (Loveridge 1944).

The carton nests are more or less spherical, most often football-sized black structures (Figure 6-5) made of chewed vegetable fibers, mixed with soil and secretions from maxillary glands of the worker ants. Internally, the nests are composed of cells with thin, papery walls, giving them a spongy appearance. Ants building carton nests often kill the leaders of the best trees in plantations of *Cupressus* (Plate 46), *Grevillea*, *Juniperus* and *Pinus* (Gardner 1957a).

Figure 6-5. Carton nest of black cocktail ants *Crematogaster* sp. (Myrmicinae). Mt. Meru.

In Tanzania, several species of cocktail ants inhabit the swollen thorn bases (stipules) of some 13 species of dry-land acacias (Sjöstedt 1910; Hocking 1970). The trees initially produce intact swellings before cocktail ants or the ponerine ant *Tetraponera penzigi* (Mayr) hollow them out from at most two, or from many holes, respectively, typically at the base of the stipule. Wind rushing by these hollow structures can produce a whistling sound, accounting for the name whistling acacia. The ants build interior partitions in these gall-like structures, in which they house their eggs, larvae and pupae (Sjöstedt 1910). African acacias also have a number of true galls (Plate 47) caused by other agents, mostly insects (Monod 1968).

The most ant-dependent species of Old World acacias is *A. drepanolobium*, a short tree with conspicuous galls that are 4-7 cm across (Figure 6-6; Plate 48). Less than 1% of *A. drepanolobium* are ant-free, making this essentially an obligate ant-acacia association (Hocking 1970). None of the East African cocktail ants is more strongly adapted to its host than are the "red heads", *C. mimosae* Santchi, to *A. drepanolobium.* Two thirds of these acacias are inhabited by this ant while a little less than one third is associated with "yellow tails" *C. nigriceps* Emery, and the remainder with *T. penzigi*, or rarely, *C. sjöstedti* Mayr. Normally only one species of ant is associated with each tree. Apart from nest sites, the tree provides the ants with two sources of food, i.e., nectar from leaf

Figure 6-6. Acacia drepanolobium with the pseudo-galls housing *Crematogaster* ants. Dark-colored galls may indicate higher elevations. August, Serengeti.

nectaries, as well as oils and proteins in little outgrowths on the anthers, which the ants harvest and take to their nest (O'Toole and Preston-Mafham 1985). In turn, the ants keep herbivorous insects in check and deter browsers. Mature swellings of *A. drepanolobium* are either dull black or bleached white, the former correlated with higher altitudes or shade, the latter with lower altitudes, apparently an adaptation to prevailing temperatures (Hocking 1970).

Unlike ants in other subfamilies, myrmicins have a two-jointed petiole. Workers of *Crematogaster* are 3-6 mm long. The queen resembles workers in shape and color but is up to 1 cm long and her abdomen is swollen. Males resemble workers, but are more slender.

Cocktail ants derive their name from the way they "cock their tail", i.e., carry their flat, pointed abdomen raised over the back when alarmed. Highly agitated when disturbed, they typically swarm in numbers, recruited by an alarm pheromone from the mandibular glands of other workers (O'Toole and Preston-Mafham 1985). They also exude a sticky, malodorous, whitish liquid from glands at the tip of the abdomen which when wiped into their bites with the spatula-like, modified stinger, causes a painful reaction (Skaife 1953, 1979). Mating flights occur in November-December. The pruning of axillary buds of the host stipules by the ants is interpreted as promoting a tree's adaptation to dry environments (Hocking 1970). Any one pseudo-gall may contain a combination of stages and sexes or just one. Workers often are found alone and eggs may be concentrated in a few swellings.

Natural enemies of cocktail ants include driver ants and birds (Sjöstedt 1910; Hocking 1970). There are also numerous associates of ant-occupied swellings, most remarkably some chrysomelid mimics of *C. mimosae* (Hocking 1970). An equally interesting adaptation is reflected in the preying mantis *Sphodromantis obscura*, discovered in Tanzania and described by Beier and Hocking (1965). This insect has an uncanny resemblance to pseudo-galls on *A. drepanolobium* and preferentially preys on cocktail ants.

2.5.2. Carebara vidua Smith.: *African Thief Ants*

The genus *Carebara* is pantropical and in Africa is represented with 11 species. Despite the common occurrence of these ants, overall evidence concerning their biology is circumstantial and there are still unsolved mysteries (Hölldobler and Wilson 1990). Some peoples in southern and eastern Africa regard the queens a delicacy eaten raw or fried, excluding the abdomen (Skaife 1979; Huis 1996).

Colonies of *C. vidua* have thousands of tiny yellow workers barely more than 1 mm long. The giant queens are up to 25 mm long and have wingspans of 50 mm. The queens (Figure 6-7) are dark-brown or black and have a bulbous thorax and large abdomen. The weight differential between queens and workers is over 4,000 (Hölldobler and Wilson 1990). The winged males are similar to the queens, but only half her size. They are covered with pale hairs and have a yellow/orange abdomen.

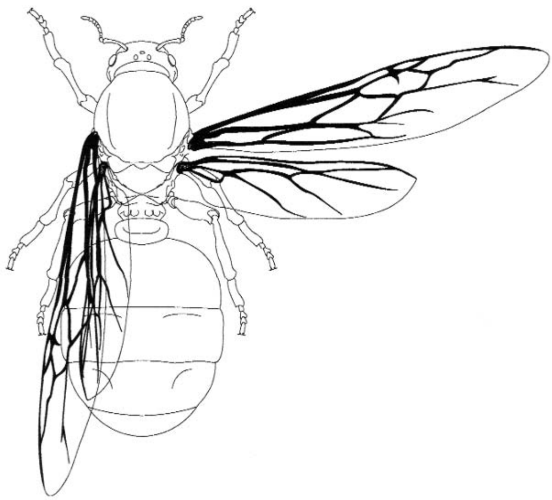


Figure 6-7. The queen of an African thief ant, *Carebara vidua* (Myrmicinae). Early January, Mangola, Eyasi.

African thief ants are exclusively associated with the nests of large termites *Macrotermes*, *Pseudacanthotermes* and *Odontotermes* (Grassé 1986), where the minute workers apparently gain access to termite eggs and nymphs and then escape with their booty through tunnels small enough to prevent soldier termites from catching up. Reports of young queens carrying workers attached to dense tufts of tarsal hair during their wedding flight, possibly to help with the founding of the new nest, appear to be a myth (Robertson and Villet 1989). Because of their subterranean existence, thief ants are rarely seen, except after the first heavy summer rains when the sun is high. At that time, large numbers of workers escape from underground through emergence holes built by the workers. After a short flight, the queen settles on a branch and releases a pheromone. Mating repeatedly, she eventually flies to the ground, sheds her wings and excavates her new nest (Robertson 1995). The huge quantity of sperm stored in her spermatheca suggests a large number of eggs. Nuptial flights continue for about 2-3 days.

2.5.3. Miscellaneous Other Myrmicine Ants

Myrmicine relatives of cocktail ants in Tanzania include some that notoriously contribute to the buildup of Homoptera on crop trees such as species of *Myrmicaria* and *Solenopsis* (Le Pelley 1959). Others, including the now cosmopolitan *Pheidole megacephala* F., are crop pests by tending Homoptera and impacting native ant faunas. Myrmicine termite predators, other than the just discussed African thief ant, include *Decamorium* spp.

3. TERMITES (ISOPTERA)

Termites are considered primitive insects. Fossil records reach back to at least 144-165 million years ago. The 286 genera and almost 2,900 species of termites are widely distributed, mostly in the warmer regions of the world (Scheffrahn 2004). Africa is termite territory *par excellence*. With approximately 170 genera (77% endemic) and at least 664 species in tropical Africa, this continent has the richest termite fauna

in the world (Sjöstedt 1900-04, 1904, 1910, 1913; Kambhampati and Eggleton 2000; Uys 2002). Morstatt (1913a) had reported only 25 termite species in German East Africa including seven new ones discovered during Sjöstedt's expedition at Kilimanjaro/Meru, but he predicted that many more awaited discovery. Indeed, Harris (1936a) following his three-year exploration of the Tanganyika territory, subsequently listed 51 species of termites, 10 new to the territory and two species new to science. Five years later, Harris (1941) numbered the then known termites in East Africa at 77 species in 19 genera including 53 species in Tanganyika. Of these 77 species, 11 were widely distributed throughout the afrotropical region, 18 were also found in the Congo and in West Africa, 8 in southern Africa, and 1 in Ethiopia. The remaining 39 were endemic to East Africa. Kemp (1955) investigated the distribution of termites in northeastern Tanzania in relation to eight vegetation zones, and found the coast had the greatest diversity in habitats and species. Twenty of the 60 species occurring there were restricted to that zone. Extremely few occurred in the cedar and evergreen montane forests of the Usambara Mountains, or on cultivated land above 1,300 m. By 1959, Le Pelley had listed a total of 124 species of agricultural and tree termites for East Africa, all but 20 of them documented for then Tanganyika. This list eventually grew to 177 species for East Africa, including 116 species in Tanzania (Weidner 1960; Wanyoni et al. 1984).

3.1. Habits

All termites are plant or fungus feeders and many rely on wood for both food and habitat. The lower termites utilize cellulose with the help of symbiotic intestinal protozoa, the higher ones employ bacteria. Others cultivate fungi in a network of combs composed of termite feces and partially digested wood to supplement other food including the aging fungal combs. Still other termites are harvesters of grass or soil feeders. Depending on species, termite nests are either entirely confined to wood (wood dwellers), or they are located entirely or partially underground (ground dwellers). Some termites construct elaborate concrete-like mounds or "termitaria" (Plate 49), while others build carton nests made of soil, saliva, fecal matter and/or woody fragments underground or in trees (Figure 6-8). Even if attacking wood above ground,

Figure 6-8. Several genera of higher termites build arboreal nests, as frequently encountered in humid coastal climates. Chalinze.

the ground dwellers usually retain nests in the soil from which they seek access to remote sources of wood. To avoid exposing themselves during these forays, many termites build earthen runways over the bark of living trees (Figure 6-9; Plate 75) or when bridging concrete basements en route to structural timbers. These foraging tubes, together with mounds, arboreal nests, swarming termites or in the case of drywood termites fecal pellets expelled to the outside, represent external signs of termite activity. Most of their tunneling in wood may go unnoticed, unless one exposes the extensive honeycombing within or the structure affected is completely hollowed out and collapses. In primitive termites, the nests tend to be irregular (diffuse), in more advanced forms the nests are concentrated and have distinctive architectures (Beeson 1961; Noirot and Darlington 2000).

Figure 6-9. Earthen runways of *Odontotermes* sp. (Termitidae) on *Delonix regia.* Morogoro.

3.2. Ecological Significance of Termites

3.2.1. Termites and Soil

Since termite biomass, ranging from less than 1 gram to over 10 grams per m^3, often rivals that of terrestrial vertebrates (Scheffrahn 2004), these insects play enormous roles in tropical ecology. They significantly contribute to nutrient cycling of dead organic matter, effectively supplementing the action of fires, bacteria and other decomposers (Abe et al. 2000). New studies indicate that soil is a significant sink for termite metabolic gases. Soils in the neighborhood of mounds tend to be enriched with clay and organic matter, and have more favorable physical characteristics, i.e., soil structure and aeration (Hesse 1955a,b). As a result, entire landscapes can be visibly shaped by the activity of termites, none more so than the so-called termite savannas and woodlands, where distinctive non-grass flora is mostly associated with the insular termite mounds dotting a sea of grass.

3.2.2. Termites and Animal Associates

Termites also provide wooden and earthen cave habitats for numerous organisms (Escherich 1909; Pearce 1998) including numerous “termitophiles”, i.e., commensal insects, mostly beetles and other arthropods (Wilson 1971; Grassé 1982-86; Kistner 1998). They are furthermore a prolific source of protein-rich food for some

indigenous people, as well as for many animals (Grassé 1986; Pearce 1998) including termite specialists such as aardvark, aardwolf, pangolin (Figure 6-2; Plate 45). Their principal predators include certain ants and *Bengalia floccosa* (Wulp), a predatory fly (Morstatt 1913a, 1922; Kemp 1955).

3.2.3. Termites and Fungal Associates

Equally as sought-after for food as the termites themselves are highly nutritious and sometimes huge mushrooms (*Termitomyces* spp.) that grow exclusively in association with termite mounds of the Macrotermitinae (Figure 6-10). These are the fruiting bodies of the termites' obligate symbiotic fungi (Heim 1977). This tropical genus of termitophile agarics (Amanitaceae) is well represented in Tanzania, where "mgunda" *T. aurantiacus* Heim, "kimelo" *T. eurrhizus* Berk. (Heim), "mkufu" *T. letestui* (Pat.) Heim, "busolele" *T. microcarpus* (Berk. & Br.) Heim (Plate 50) and "impora" *T. singidensis* are among the most highly prized mushrooms (Härkönen et al. 1995). Termites actively disseminate their symbiotic fungi either by inoculating propagules near the mound or by ingesting them. For instance, reproductives of *Microtermes usambaricus* Sjöst. are known to eat conidia of *Termitomyces* before embarking on their nuptial flight. Fungal propagules survive in their guts, until a new fungal comb is built by the workers at the new site about 10-11 weeks later, and the female inoculates the comb with the fungus.

Figure 6-10. The edible termite mushroom *Termitomyces (Eutermitomyces) letestui* growing out of a mound of *Macrotermes* sp. from fungus combs *in situ.* (Reproduced from "Biology of termites Vol 2, Krishna and Weesner (eds.) Sands (1970) The association of termites and fungi, 495-524", with permission from Elsevier).

3.3. Description and Life History

3.3.1. General Characteristics

As an order, termites have typical chewing mouthparts, straight, beaded to thread-like antennae, usually four tarsal segments, and often a pair of small cerci. The order's name Isoptera refers to the two pairs of equal-sized wings, which are delicate, held flat and extend beyond the tip of the abdomen. Termites are polymorphic, i.e., one species has several castes, each differing in appearance and performing different

tasks with the indisputable logic of a computer. These include workers, soldiers and reproductives (Morstatt 1913a; Harris 1940b) (Figure 6-11). Factors affecting caste formation include gender, pheromones, nutrition and/or sensory stimuli. With the exception of some queens, that may reach a length of over 100 mm at maturity, termites tend to be small to medium-sized insects of less than 25 mm.

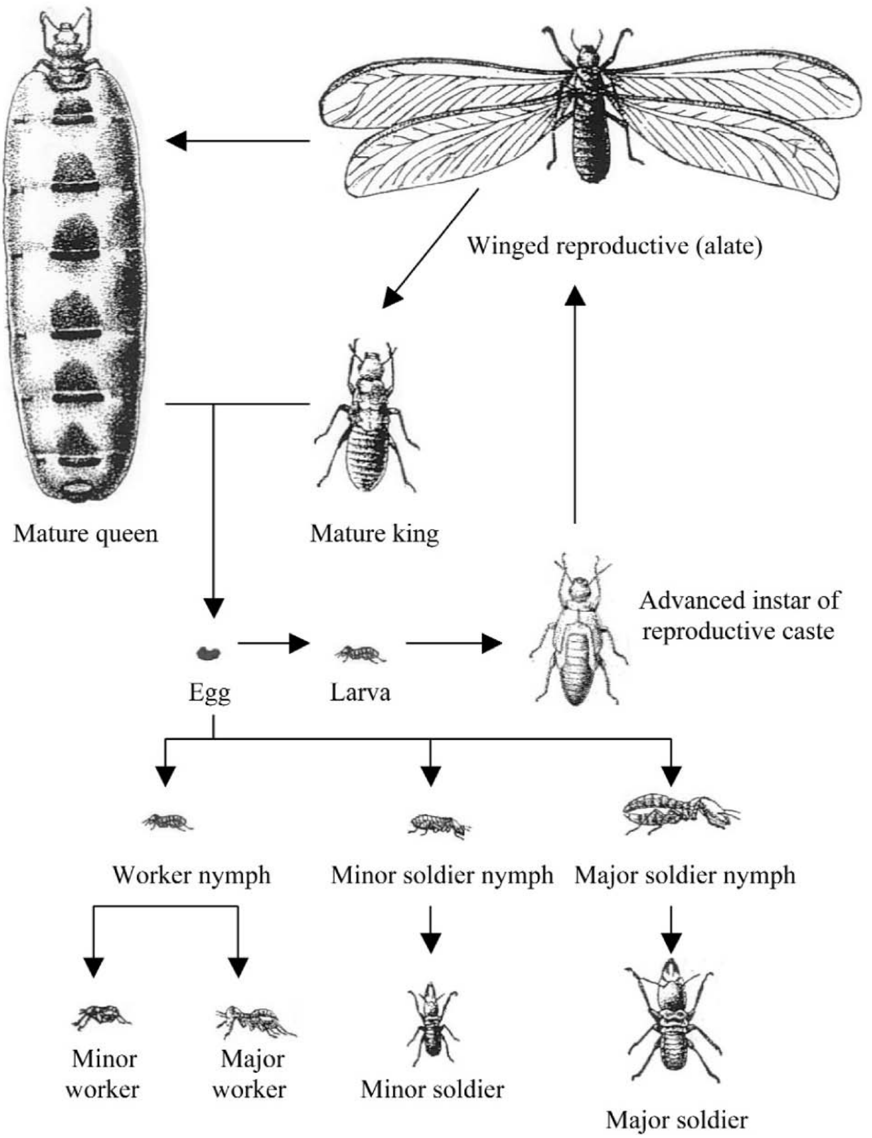


Figure 6-11. Schematic life cycle of *Macrotermes* sp. (Termitidae), showing all castes except secondary reproductives. (From Morstatt 1913c; modified).

Depending on family and species, queens of wood-feeding termites lay from 12 to over 48,000 cylindrical eggs per day, for a possible total of over 10 million in a single year, or around 100 million in a lifetime, as calculated by Escherich (1909) for *Macrotermes*, common termites in much of sub-Saharan Africa.

3.3.2. Castes

Immature termites of different castes are called larvae in the lower, undifferentiated instars and nymphs in the advanced instars of the reproductive forms. They molt at least three and as many as ten times before becoming sterile workers, soldiers or fertile adults (reproductives). Only nymphs of the latter exhibit wing buds.

Workers are generally the most numerous members of a colony and include both sexes. They are typically white, mostly unsclerotized individuals responsible for foraging, tending other castes and nest building. In many species, workers of either sex share chores, in others they may have different tasks (Pearce 1998). In certain species, there may be workers of two distinct sizes (“majors” and “minors”). In drywood termites there are no workers at all, only nymphs or so-called “pseudergates”.

Soldiers defend the colonies against intruders. Like the workers, they are sterile males or females and in some species appear in two or even three distinct sizes. They are usually slightly larger than the workers and are mostly blind and white, except for their oversized, sclerotized heads. Soldiers of some species are equipped with huge, often asymmetrical mandibles, while others have either frontal glands (“fontanelle”) or nose-like projections (“nasus”) that emit sticky, repellent or toxic substances in their chemical war against attackers (Quennedy 1975). In some termite colonies soldiers may make up as much as one fourth of the population, in others they are fewer, and some species lack soldiers altogether.

Primary Reproductives are fully sclerotized kings and queens. In most species, they have compound as well as two simple eyes. These royals initially resemble each other and are equipped with two pairs of wings, during which time they are called “alates”. They are also referred to as “rainflies” because the waves of dispersing squadrons are often synchronized with the arrival of rains. However, flights for different species of termites in eastern Tanzania were recorded in all months except July and August (Krishna and Weesner 1970). After a short flight, female reproductives shed their wings retaining only triangular stubs called “scales”, and attract mates with the help of pheromones. Males also shed their wings as soon as they have found a mate (Figure 6-12). During their “engagement”, the male follows the female in tandem (Plate 51). Once a suitable site is found, they jointly excavate space to start a new colony. After some time, mating takes place in the new royal cell that effectively becomes a prison the two will never leave. They care for their first offspring until the first, early instar larvae take over the routine chores of the growing colony. Because of her growing ovaries, the abdomen of mature, egg-laying queens often becomes huge (Figure 6-13). In the process, the inter-segmental membranes stretch

to an extent that the abdominal sclerites are widely separated as small, brown islands in an expanse of soft, white skin thin enough to see the pumping heart. These queens, frequently described as “bloated sausages” or “gross egg-laying machines”, eventually become so obese that they cannot move on their own. Unlike social Hymenoptera, the two royals remain together in their fortified chamber for years and possibly decades, mating intermittently. A colony usually contains but one queen, although up to eight have been found, and rarely, two queens share one royal chamber.

Figure 6-12. Shed wings of a swarm of reproductives of *Odontotermes* sp. (Termitidae) attracted to a door light. April, Olmotonyi.

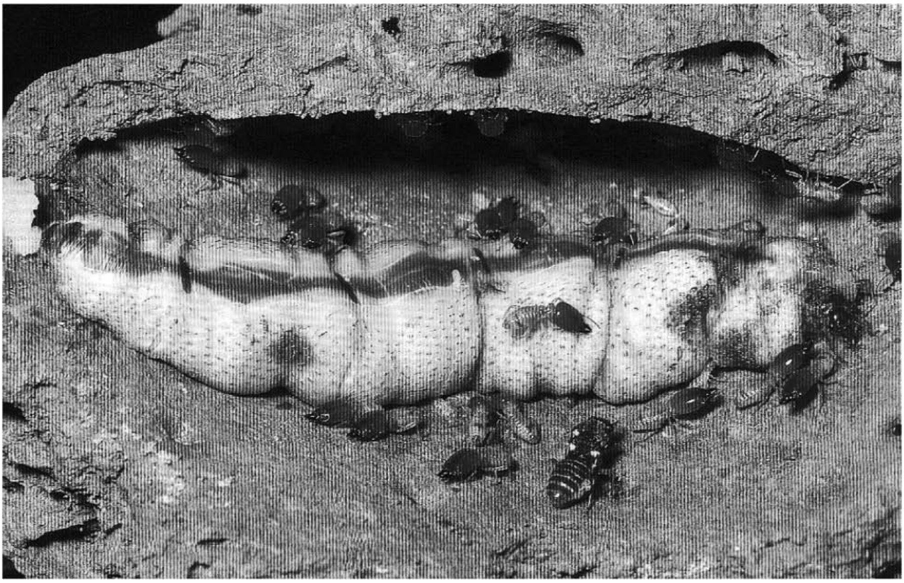


Figure 6-13. Mature queen, king (front right) and soldiers of *Macrotermes falciger* (Termitidae) in royal cell (Photo: L. Lemaire. From Malaisse (1997) Se nourrir en forêt claire africaine. Approche écologique et nutritionelle; by permission of Les Presses agronomiques, Gembloux, Belgium).

Secondary reproductives, also called “neotenics” or “supplemental” reproductives, only occur if something should happen to a single queen. These are small-eyed, weakly sclerotized, modified female workers that develop only non-functional wing buds. Up to 200 secondary reproductives and, rarely, even tertiary reproductives may occur in a colony.

3.3.3. Identification

Termite classification is to a large extent based on the appearance of reproductives or soldier castes, with emphasis on wing venation, antennae, mandibles, digestive tubes, eyes and the frontal gland called fontanelle. Numerous taxonomic changes through the years account for much of the confusion with names. For instance, *Cryptotermes dudleyi* Banks has been described under at least seven generic names. Many termite genera in Africa are considered in need of taxonomic revision (Uys 2002).

Of the seven families of termites worldwide, two are restricted to Australia and South America, respectively. One family attacks only wet, rotten wood and, in Africa, occurs in only two species restricted to South Africa. The four remaining families of termites are commonly found in Tanzania, as well as in much of sub-Saharan Africa. Traditionally, keys for termite identification were mostly based on alates and soldiers (Table 6-2), which allows application under field condition. The use of recently developed keys for the identification of worker castes of termite genera from the soils of Africa is more complicated, as they not only rely on mandibles, but on internal characteristics as well (Sands 1998).

Table 6-2. Key to the families of Isoptera in Tanzania.

Alates	
1 Anterior wings stubs short; wings with limited reticulation	Termitidae
Anterior wings stubs cover at least the base of posterior scales	2
2 Simple eyes (ocelli) absent	Hodotermitidae
Simple eyes present	3
3 Fontanelle present, but may be difficult to see; left mandible with two subapical teeth	Rhinotermitidae
Fontanelle absent; left mandible with three subapical teeth	Kalotermitidae
Soldiers	
1 Pigmented eyes and large abdominal cerci	Hodotermitidae
Eyes absent or unpigmented; cerci absent	2
2 Pronotum as wide as head capsule	Kalotermitidae
Pronotum narrower than head capsule	3
3 Pronotum flat without anterior lobes	Rhinotermitidae
Pronotum saddle-shaped with anterior lobes	Termitidae

3.4. Termites in Forestry

While overall termites play extremely beneficial ecological roles, about 10% of species worldwide are considered pests (Pearce 1998), with the bulk of damage being attributable to fewer than 2% of species (Scheffrahn 2004). More specifically, termites can become forest pests in three major contexts (Morstatt 1913a; Sangster 1956; Wilkinson 1965; Harris 1971; Becker 1976, 1977).

3.4.1. Impact on Young Trees

Many of the higher termites (Termitidae) and occasionally harvester termites (Hodotermitidae) injure and kill living seedlings and saplings by ring-barking them on or just below the surface, or by destroying the roots (Morstatt 1913a; Wilkinson 1965; Selander and Bubala 1983). This is the biggest pest problem in exotic tree nurseries and plantations in semiarid Africa during the dry season, foremost for eucalypts but also for agricultural crops (Brown 1965; Wilkinson 1965; Bigger 1966). In East Africa, the most seriously affected regions are round Lake Victoria into Central and Western Uganda, as well as in Machakos District, Kenya and Iringa, Tanzania (Wilkinson 1965). Factors accounting for attacks on new plantations are very complex, including species and condition of trees, species of termite, soil type, food alternatives, moisture content, altitude, temperature and other climatic elements. Under most conditions, unhealthy trees are the most susceptible, but this is not an absolute requirement, as very healthy trees may also suffer severely under certain circumstances.

3.4.2. Impact on Larger, Living Trees

Certain termites also attack sound wood in living trees, damage occurring in restricted (Kalotermitidae) and free-range (Rhinotermitidae and Termitidae) categories (Wilkinson 1965). Drywood termites are restricted to one tree, gaining access through dead branches, scars and fire damage. They generally remain confined to dead wood, but some make incursions into living sapwood and beyond, into heartwood. The majority of injurious termites are free ranging, i.e., they attack several trees from an external base connected through subterranean tunnels or earthen runways.

3.4.3. Impact on Structural Wood

Structural timber in buildings, fences, telegraph poles, railroad ties, dams, furniture, pianos and such (Figure 6-14), as well as anything containing cellulose and sometimes other organic substances is likely to be attacked by various drywood (Kalotermitidae), subterranean (Rhinotermitidae), and higher termites (Termitidae), (Morstatt 1913a; Harris 1943, 1971; Becker 1976). For instance, before renovation, books and other documents in the Tanzanian National Archives in Dar es Salaam suffered serious damage from termites, frustrating researchers by eliminating portions of irreplaceable documents (Schabel 1990). Structural pest termites are often the same species as those associated with snags, dead branches and stumps or the exposed wood on living trees in nature.

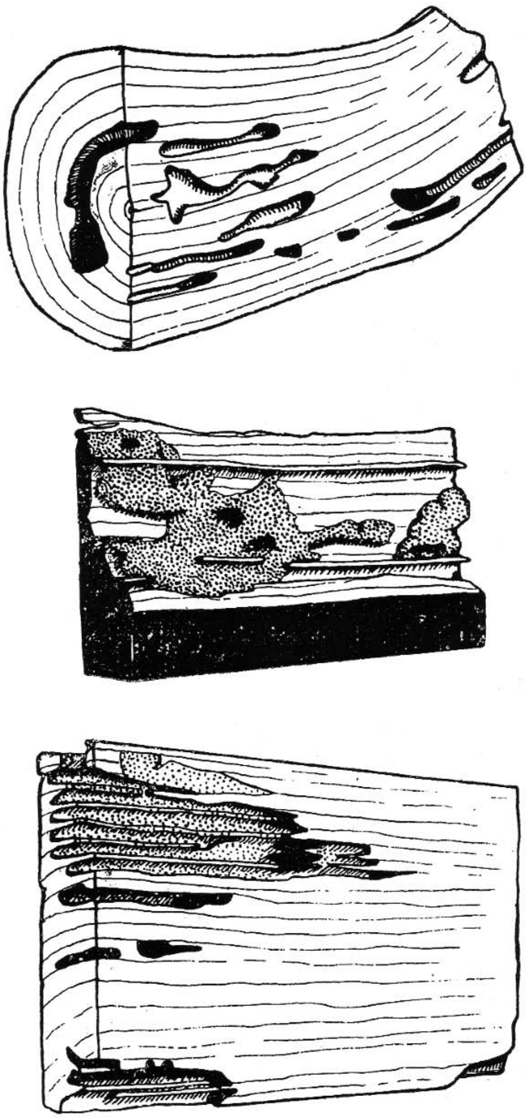


Figure 6-14. Structural damage by various termites to timberwork in buildings. A. Drywood termite *Cryptotermes* (Kalotermitidae) galleries in roof pole. B. Damage by *Microtermes* (Termitidae) in door of imported, painted but not treated timber. C. Damage by *Coptotermes amanii* (Rhinotermitidae) in untreated, imported ceiling boards. (From Harris 1943, reproduced by permission of Director, Kenya Agricultural Research Institute – KARI).

3.5. Major Termites of Tanzania

3.5.1. Hodotermitidae

Two species of Old World harvester termites are widely distributed in dryland Africa and parts of Asia. With lengths of over 15 mm, these are fairly large termites. All castes have compound eyes but at most rudimentary ocelli. There are no fontanelles. Soldiers have robust mandibles and antennae are composed of 23-31 antennal segments. These termites are more sclerotized than most others, which makes them less susceptible to desiccation and thus allows foraging excursions outside the nest even during the day. They feed mostly on grass, although minor damage to young trees and shrubs has also been reported (Wilkinson 1965). Their deep subterranean nests are difficult to find, and there are no mounds. In parts of Africa, grass seeds stored by these termites in underground chambers are collected by locals and used for food and the brewing of beer.

3.5.2. Kalotermitidae

The so-called drywood and dampwood termites occur throughout the (sub)tropics (Eggleton 2000). There are 45 species in tropical Africa, and six genera in East Africa (Harris 1950; Kambhampati and Eggleton 2000). While under natural conditions these termites contribute to the breakdown of dead trees and branches, some

cause concern when they attack not only structural wood (Plate 76) and various wood products, but anything containing cellulose. In other parts of the tropics, some species have occasionally damaged certain tree crops by moving from dead wood into living tree parts (Weidner 1988).

Drywood termites live confined to galleries in dry or slightly moist (15-20%), sound wood of seasoned timber, logs, dead branches and structures that have no direct ground contact. Colonies are small, composed of a few hundred to a few thousand larvae, occasional soldiers and the reproductives. There is no worker caste.

These medium-sized, brownish termites resemble harvester termites. Their reproductives have simple eyes, no fontanelles and antennae with fewer than 21 segments. Virgin reproductives have wings with three or more heavy longitudinal veins at the anterior margin. There are no special royal chambers and the queen produces only about 12 eggs a day. As a result, colonies build up slowly without giving much external evidence of their presence. Periodically however, the normally plugged exit holes are opened to expel dry, hexagonal fecal pellets the size of poppy seeds (Figure 6-15) that pile up in telltale small heaps beneath the infested wood. This accounts for generally clean galleries. Only the reproductives venture outside for their dispersal flight. Soldiers typically have strongly developed mandibles and often short, truncated (phragmotic) heads used to plug tunnel entrances (Figure 6-16).

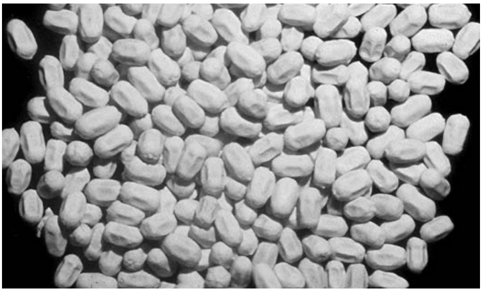


Figure 6-15. Scanning electron micrograph of fecal pellets by *Cryptotermes brevis* (Kalotermitidae). (Reproduced by permission of R Scheffrahn, University of Florida).

Despite intrinsically limited mobility, some of the drywood termites have expanded their range considerably, even internationally, by hitching rides on infested ships and wood products (Krishna and Weesner 1970).

Major Drywood Termites of East Africa. Only one genus, *Cryptotermes*, is of major concern, less for deteriorating dead trees, than for damage in structural wood. Reproductives of these termites have antennae with 14-16 segments and iridescent wings with the medius and radius sector meeting in the distal half. Three species in East Africa are of interest.

Cryptotermes brevis Walker is of neotropical origin. It is considered a completely domesticated termite and one of the most destructive of structural pests (Krishna and Weesner 1970). Records exist from Hong Kong, the southern USA, Canada and some Pacific Islands. Although this termite has not been found in Tanzania, it has been thoroughly entrenched in South Africa since 1918, and there have been isolated

finds in 11 other African countries, including Cape Verde, Zaire, Egypt, Gambia, Ghana, Madagascar, Nigeria, St. Helena, Senegal, Sierra Leone and Zimbabwe (R Scheffrahn, pers. comm.). There has been one report of it having “possibly” surfaced in Uganda (Campbell 1974). As a result, this termite must be considered a potential invader of Tanzania.

Figure 6-16. Scanning electron micrograph of the phragmotic head of a *Cryptotermes brevis (Kalotermitidae)* soldier. (Reproduced by permission of R Scheffrahn, University of Florida).

Cryptotermes dudleyi Banks, the drywood termite, accounts for most structural damage in East Africa including stored *Podocarpus* timber. This termite is of oriental origin and now widely spread in neotropical America, Southeast Asia, northern Australia, and Sri Lanka (Krishna and Weesner 1970). It was first reported in 1950 in stored timber at Tanga and subsequently became thoroughly entrenched along the East African coast from Somalia to the Rovuma River, including Zanzibar (Gardner 1957a). It also occurs in Uganda, Mauritius and Madagascar.

Cryptotermes (=Calotermes) havilandi Sjöstedt is apparently a native of Africa from Kenya to Zululand, but is now also common in Madagascar, the Comoro Islands, from the Congo to West Africa, Trinidad, British Guyana, Brazil and parts of Asia. This termite (Figure 6-17) typically occurs in dead branches, fallen wood or stumps but rarely in houses. Records of this termite from buildings in Dar es Salaam and Mombassa may be based on misidentification of *C. dudleyi*. In May this termite is on the wing in eastern Tanzania (Krishna and Weesner 1970).

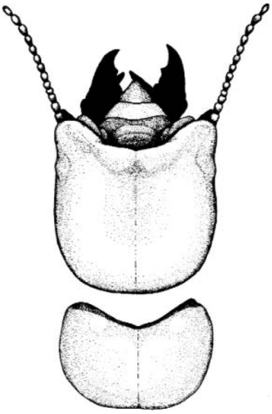


Figure 6-17. Dorsal view of head and pronotum of *Cryptotermes havilandi* (Kalotermitidae). (From Uys 2002, reproduced by permission of GL Prinsloo, Agricultural Research Council, Pretoria, SA).

Miscellaneous Other Drywood Termites. The remaining genera of dry-wood termites occurring in Tanzania (*Bifiditermes (=Kalotermes, Procryptotermes), Epicalotermes (=Kalotermes), Bicornitermes (=Calotermes), Glyptotermes* and *Neotermes*), the latter two being pantropical, include seven mostly “wild” species found in fallen logs or

dead branches on trees. They were listed and some illustrated by Sjöstedt (1926), Harris (1941, 1950), Kemp (1955), Wilkinson et al. (1965) and Weidner (1988). Only *Bif. (=Kalotermes) durbanensis* (Haviland) (Figure 6-18) is of slightly greater concern than the others, as it has damaged buildings and in trees may go from dead into live wood (Wilkinson 1965; Weidner 1988). This termite has spread and now occurs from Tanzania to South Africa.

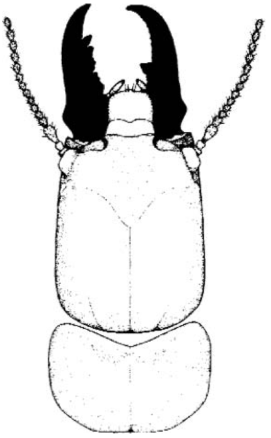


Figure 6-18. Dorsal view of head and pronotum of soldier of *Bifiditermes durbanensis* (Kalotermitidae). (From Uys 2002, reproduced by permission of GL Prinsloo, Agricultural Research Council, Pretoria, SA).

3.5.3. Rhinotermitidae

Insects in this family are called the "lower subterranean termites", or simply "subterranean termites" to differentiate them from other ground-dwelling termites, especially the "higher subterranean termites" in the family Termitidae.

Rhinotermitids occur throughout the tropics and into the temperate zone. They are commonly found in old tree stumps and buried timber but also excavate pipes in the heartwood of mature trees, and attack buildings. They destroy wood in a layered, lamellar fashion with denser wood remaining as walls, floors and ceilings of a series of compartments. Infested wood typically contains soil, or a mixture of soil with chewed wood, and the gallery walls are covered with a pasty-looking wood pulp.

These termites are less than 5 mm long. All castes have frontal glands (fontanelles) that are conspicuous in soldiers. When alarmed, soldiers exude a drop of sticky fluid from this gland. Soldiers have a flat pronotum and antennae with 14-22 segments. The wings of reproductives have two heavy longitudinal veins in the anterior margin. Front wing stubs are longer than the pronotum.

Subterranean termites live in large colonies in fixed nests underground. They do, however, range as far as 100 m from this primary nest commuting through foraging tubes made of chewed wood and soil. Satellite nests may be maintained in trees and buildings, but remain connected to the primary nest by runways. Because of their need for high wood moisture, Rhinotermitidae may survive in ships' timbers. As a result, some of them have become pests far from their place of origin.

Major Subterranean Termites of East Africa. There are 14 African species of Rhinotermitidae and two genera with two species each occur in Tanzania.

The pantropical genus *Coptotermes* sports an extensive record of introductions through various ports of entry. For instance, the oriental *C. formosanus* Shiraki has become established as a structural pest in subtropical South Africa (Harris 1966) and,

in 1960, was discovered on a fisheries research ship moored in several East African ports (Wilkinson 1965). The soldiers in this genus have highly developed fontanelles.

Two indigenous species, *Coptotermes sjöstedti* (Holmgren) and *C. amanii* (Sjöst.) (Figure 6-19) prefer dead tree roots or wounds near the collar of standing trees where carton nests with a thick-walled, central queen cell are constructed (Harris 1941, 1966).

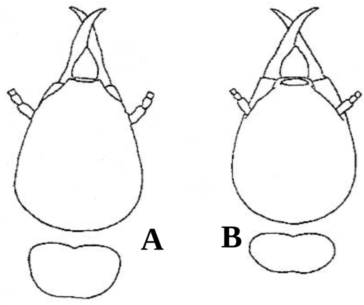


Figure 6-19. Head and pronotum of soldiers of (A) *Coptotermes amanii* and (B) *Coptotermes sjöstedti* (Rhinotermitidae). (From Harris 1966; reproduced by permission of The Royal Entomological Society of London).

C. sjöstedti occurs in western Tanzania and is most prevalent in West Africa, where it accounts for much damage to buildings and timbers (Harris 1966). In 1999 it was documented as the first African endemic termite to become established in the Americas (Scheffrahn et al. 2004).

C. amanii, which occurs from Somalia through East Africa to Zimbabwe and now also South Africa, is best known to attack badly pruned, mature trees used in agro-forestry or as ornamentals, such as *Samanea saman,* but has also been documented damaging old seasoned timber in buildings in Tanzania, Kenya and adjacent islands (Gardner 1957a; Harris 1966). It occurs at altitudes up to 1,000 m. Its flight in eastern Tanzania is in November (Krishna and Weesner 1970).

Schedorhinotermes (=Rhinotermes) spp. This genus is widespread not only in Tanzania but in the Afrotropics altogether (Harris 1941, 1971). It normally inhabits tree stumps and rotting logs, but can also do serious structural damage and attack mature trees through wounds. *S. putorius* Sjöst. and *S. lamanianus* Sjöst. have soldiers of two sizes with little resemblance to each other, one with large mandibles, the other with an extended labrum. The reproductives have a circular head, and a slightly drawn out or markedly arched clypeus.

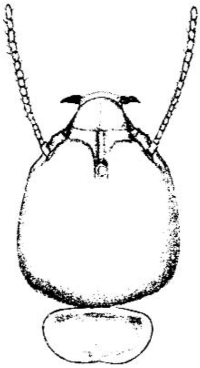


Figure 6-20. Head and pronotum of major soldier of *Schedorhinotermes lamanianus.* (Rhinotermitidae). (From Sjöstedt 1926).

The golden tree termite *S. lamanianus* (Sjöst.), routinely attacks mature trees in many species, and is particularly conspicuous in *Delonix, Dalbergia, Jacaranda, Manihot* and *Persea americana* in cities in warm, moist coastal climates, as well as in gallery forests (Gardner 1957a). The main nest tends to be at the base of trees, with occasional subsidiary carton nests above (Kemp 1955). It may have many subsidiary nests in neighboring trees connected by tunnels (Pearce 1998). Of the two types of soldiers, the larger ones (Figure 6-20) are less common.

3.5.4. Termitidae

The huge family of so-called “higher termites” makes up about 80% of termite species, including 601 African species (Kambhampati and Eggleton 2000). Certain species occur in enormous colonies of sometimes more than 1,500,000 individuals that may have existed for 80 years or more.

Workers in this family are blind. Many species have nasute soldiers, and in one subfamily there are no soldiers at all. The pronotum of soldiers and workers is narrow and has a raised median lobe in front. Wings of reproductives are similar to those in Rhinotermitidae, i.e., they have two heavy, longitudinal veins at the anterior margin, but the front wing stubs in the Termitidae are shorter than the pronotum.

Most Termitidae are wood eaters, but some also damage agricultural crops, especially during the drier part of the growing season, and some feed on soil, grass, dung and other vegetable matter. Most live entirely or partially underground. Included are mound builders, fungus growers and guest termites that cohabitate with other termite species. There are subterranean nests made of wood carton, partially subterranean concrete-like mounds, and arboreal nests. These termites tend to remove wood en masse, but to retain the rigidity of the structure they are hollowing out, they fill the void spaces within the remaining thin, outer layer with packed earth. Wood below ground or encased in masonry tends to disappear entirely. Mound builders start below ground before building turreted, buttressed castles (termitaria) sometimes extending to a towering 12 m above ground level (Bölsche 1931). These act as respiratory devices to capture wind energy for ventilation (Figure 6-23). Depending on soil, climate and other factors, mound shapes vary in the same species, but genera tend towards predictable architectural types (Noirot and Darlington 2000).

Significance to forestry. For forestry in East Africa, this is the most troublesome family of termites (Atkinson 1989; Wilkinson 1965). Different species cause serious damage to natural regeneration, seedlings in nurseries and young, recent transplants until crown closure occurs, but mature trees can also be affected. During a drought in German East Africa, higher termites caused very serious damage in 4-5 year old rubber tree and black wattle plantations (Morstatt 1913b). In older rubber trees that had been tapped, damage was done to the bark, cambium, trunk wood, root collars and roots, often killing trees or leading to breakage or wind throw. In black wattle, girdling at the root collar occasionally occurred. The most common structural termites from this family include *Macrotermes subhyalinus* Rambur, *Odontotermes badius* (Hav.) and *Microtermes redenianus* (Sjöst.) (Harris 1943). In Zambian plantations, the major termite pests notoriously belong to 10 genera of Termitidae, including *Allodontotermes*, *Amitermes*, *Ancistrotermes*, *Anoplotermes*, *Macrotermes*, *Microcerotermes*, *Microtermes*, *Odontotermes*, *Pseudacanthotermes* and *Synacanthotermes*, all of which are shared by Tanzania. These termites cause damage in seven distinct patterns (Figure 6-21) (Selander and Bubala 1983).

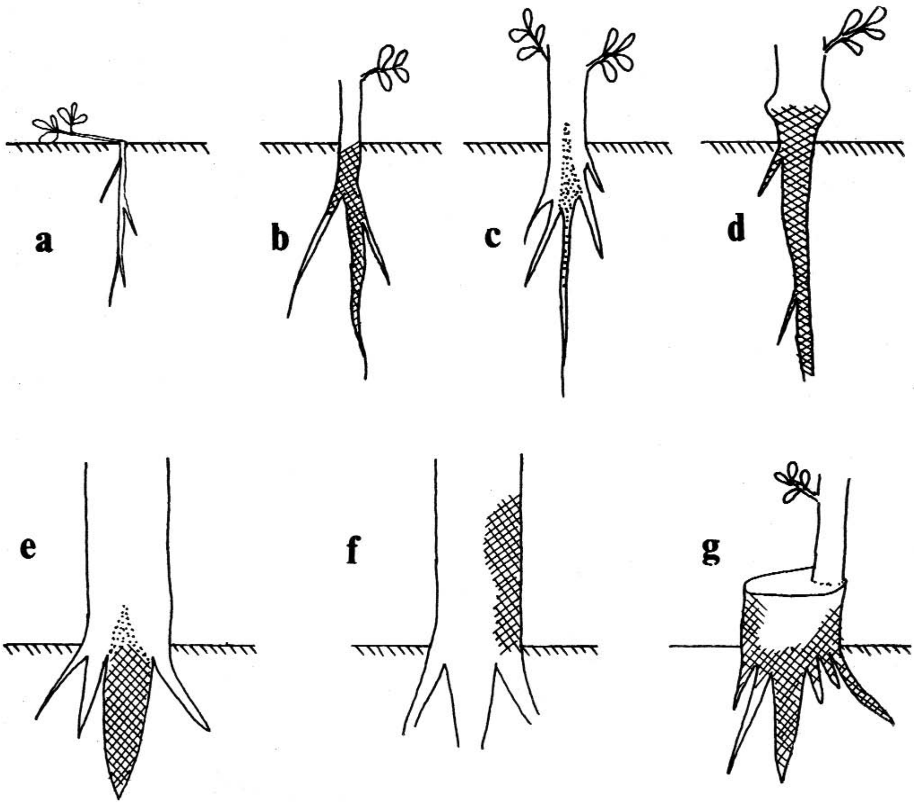


Figure 6-21. Different patterns of termite damage to eucalypts caused by a variety of termite genera. Crosshatching indicates superficial, dotting internal feeding. (From Selander and Bubala 1983).

Given the large numbers of genera and species in this family, it is convenient to discuss the more conspicuous or economically important higher termites which belong to four subfamilies, i.e., the Macrotermitinae, Apicotermitinae, Termitinae and Nasutitermitinae. The taxonomy of these termites has experienced major revisions during the past decades, although it is still very much in flux for some groups (Kambhampati and Eggleton 2000).

Subfamily Macrotermitinae. The stronghold of the fungus-farming termites is semi-arid to arid land in the Old World tropics, especially Africa, where 165 species occur (Eggleton 2000; Kambhampati and Eggleton 2000). Seven of the above-mentioned important genera belong to this subfamily of termites, making it the single most important group of termites for field forestry in Africa. Included are the "big 5" genera, i.e., *Macrotermes, Odontotermes, Pseudacanthotermes, Ancistrotermes and Microtermes* (Wood and Pearce 1991). The first three usually attack plants externally,

the latter two internally. On semiarid sites in East Africa with a history of overgrazing, deforestation and over-reliance on exotic plantations, field damage to tree seedlings, especially by species of *Macrotermes, Odontotermes* and *Microtermes* is almost predictable. These three genera occur not only in Africa, but also in other parts of the Old World tropics.

The Macrotermitinae are not associated with symbiotic protozoa, but cultivate fungi either underground or in their mounds (Wood and Thomas 1989). Their soldiers sport formidable, sabre-like mandibles and have a saddle-shaped pronotum. They have a rounded labrum with hyaline tip and mandibles with few teeth (Pearce 1998). Reproductives have a labrum longer than broad and a chitinous, transverse band.

Ancistrotermes. Most of the ten species in this genus are endemic to savannas in the afrotropical region (Coaton and Sheasby 1975; Eggleton 2000). They are small termites resembling *Microtermes*, but their soldiers have more robust, toothed mandibles. These termites live in subterranean nests composed of several, less than 10 cm long, subspherical cells each containing a rosette-like fungus comb. They are pests in nurseries and attack young trees in agroforestry or in the field. Some are also known as structural pests in wood already subject to a degree of fungal deterioration. *Ancistrotermes latinotus* (Holmgren) (Figure 6-22) attacks wood, damages crops in the miombo zone of southern Tanzania and in semiarid country routinely causes problems for seedlings in the 6-21 c, f patterns (Kemp 1951; Bigger 1966; Harris 1971; Selander and Bubala 1983). In eastern Tanzania this termite flies in February and October (Krishna and Weesner 1970).

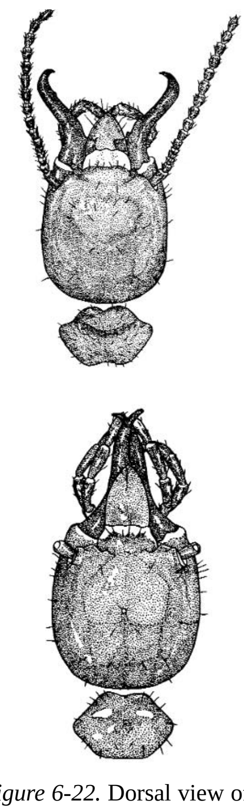


Figure 6-22. Dorsal view of head and pronotum of major (above) and minor soldier of *Ancistrotermes latinotus* (Termitidae). (From Uys 2002, reproduced by permission of GL Prinsloo, Agricultural Research Council, Pretoria, SA).

Macrotermes (=Bellicositermes; Termes). This genus is widely distributed in tropical Africa and Asia and includes some of the largest termites. Winged forms of *Macrotermes falciger* Gerst. have wingspreads up to 88 mm and their bodies can measure 22 mm, or up to 45 mm from head to the wing tips (Morstatt 1913c). Mature queens may be over 100 mm long. Soldiers and workers are, however, much smaller, measuring only about 20 and 11 mm, respectively. *Macrotermes* soldiers are derived from female nymphs, while in other genera soldiers may be sterile males and females, and in still others only males. The mandibles of soldiers are without teeth.

The huge colonies of *Macrotermes* live in very large mounds built of sand and clay mixed with saliva. Most of these termitaria reach above-ground and are equipped with vertical chimneys (Figure 6-23), but also contain underground corridors and caves (Noirot and Darlington 2000). The fungus gardens, grouped around a substantial queen cell, are composed of spongy grey-brown "combs" made of digested plant matter and feces. In eastern Tanzania, *Macrotermes* usually fly in December (Krishna and Weesner 1970).

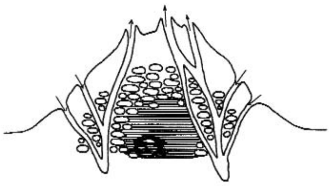


Figure 6-23. Diagrammatic vertical section through the vented mound of *Macrotermes subhyalinus* (Termitidae). The bubbles indicate fungal combs and the dark area shows the royal chamber embedded in the core of the nest (From Noirot and Darlington 2000; modified).

These termites attack sound wood, including living but unhealthy trees, as revealed by sheet-like earthen tubes on trunks. Next to, and in concert with drought, they are considered the most significant obstacle to the culture of eucalypts and other trees in the drier parts of Africa often destroying entire populations of seedlings in their first year and even larger tree crops (Mansfield-Aders 1919/20; Selander and Bubala 1983). On Zanzibar, older clove trees were attacked, and 50% of some coconut seedbeds were destroyed by *Macrotermes (*Mansfield-Aders 1919/20). In the 1980s, when Malawi heavily relied on eucalypts for an ambitious fuel wood plantation program, they were considered "THE major entomological problem in forestry" in that country (DW Barnett, pers. comm.).

Two species of *Macrotermes, M. subhyalinus* (= part *M. bellicosus* (Smeath.)) and *M. falciger (=M. goliath)* are important in Tanzania. Ruelle (1970) revised this genus for the afrotropical region, cleaning up much confusion concerning a cluster of 23 species and 11 forms or varieties found in the literature, many of them synonyms. He gave one former variety species status and split one species into two, leaving 12 recognized and re-described species. According to this new scheme, the most widely distributed species in Africa, after the splitting of *M. natalensis* into *M. bellicosus* and *M. natalensis* (Hav.), is *M. subhyalinus,* replacing the former *M. bellicosus* (Ruelle 1970). The new *M. bellicosus* (Smeath.) occurs from Senegal to Uganda, has one isolated record from Tanzania, and is well represented throughout the Zaire basin. *M. subhyalinus* tolerates drier conditions than does *M. bellicosus* and is common in the northern half of Tanzania. The second common and most important species in Tanzania, *M. falciger* (Gerst.) replaced the former *M. goliath* and occurs from Uganda and Tanzania southward into South Africa. Their mounds are enormous. This species commonly makes bark tunnels. *M. falciger* is considered THE most dangerous among the ten important plantation Termitidae in Zambia (Selander and Bubala 1983), killing all ages of eucalypts. Even the taproots of the most vigorous young trees are devoured in the 6-21d pattern. *M. ukuzii* Fuller is restricted to the western part of Tanzania (Ruelle 1970). The new *M. natalensis* (Haviland) is mostly southern African, reaching as far North as Zambia and Mozambique.

Microtermes, as their name suggests, are very small insects. They are widely distributed in tropical Asia and Africa (Eggleton 2000). In Africa alone, there are 42 species of these most common of the small fungus growers. Their population densities in the upper 1 m of soil may reach over 4,000 m² per meter, especially in intensely cultivated areas. From their diffuse, subterranean nests these termites attack sound wood, occasionally in buildings. In an experiment in Shinyanga, they were among four main species of termites attacking wood (Kemp 1951). They can also become noxious in nurseries and on young trees. In Zambia (Selander and Bubala 1983) at least three species attacked eucalypts of any size in the 6-21b, e and g patterns. Soldiers have smooth mandibles.

At least six species of *Microtermes* are known in Tanzania, mostly in conjunction with dead wood. They include *M. (=Microcerotermes) alluaudanus* Sjöst., *M. luteus* Harris (Figure 6-24), *M. magnoscellus* Sjöst., *M. redenianus* (Sjöst.), *M. usambaricus* Sjöst. and *M. vadschaggae* Sjöst. Among these, *M. redenianus* may be the most important, as it attacks both structural wood and young planted trees (Harris 1943; Gardner 1957a). There are workers and soldiers in two sizes (Sjöst. 1926). *M. alluaudanus* was reported to fly in eastern Tanzania from October to December (Krishna and Weesner 1970).

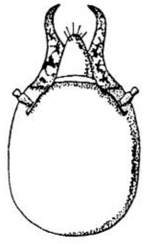


Figure 6-24. Head of soldier of *Microtermes luteus* (Termitidae). (From Harris 1961).

Odontotermes (=Termes) make up another important group of widely distributed fungus growers (Eggleton 2000). There are 78 species in tropical Africa and others in Asia. Together with *Microtermes* spp., they are the most abundant termites on cultivated land (Kemp 1955). These are large termites, only somewhat smaller than *Macrotermes,* but they engage in little or no mound building. There are a variety of nest types, some in trees. These termites differ morphologically from *Macrotermes* by having only one soldier caste which is equipped with a marginal tooth on the inner edge of the left and sometimes also on the right mandible. Most important in East Africa, as well as other parts of Africa, are *O. badius* and *latericius,* both serious destroyers of structural wood, seedlings and young trees (Harris 1971). In Zambia, at least eight species of *Odontotermes* attacked all kinds of eucalypts in the 6-21b, e, f and g patterns (Selander and Bubala 1983).

O. (=Termes) badius (Haviland) builds subterranean nests that reveal themselves only with an inconspicuous soil elevation without ventilation shafts. The nests (Figure 6-25) are often found under buildings (Gardner 1957a). This is the most common termite in East Africa and, in South Africa, may be the worst of the subterranean termites in terms of destructiveness (Skaife 1979). Transplanted trees are also attacked.

O. (=Termes) latericius (Haviland) (Figure 6-26) is also very abundant in dead wood throughout Central, East and southern Africa, in East Africa causing mainly

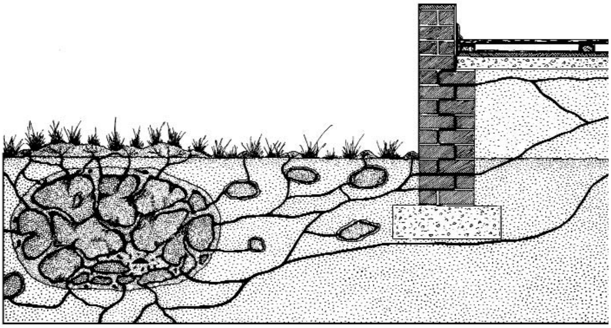


Figure 6-25. Infestation of a house from a nest of *Odontotermes badius* (Termitidae) situated extramurally. (From Uys 2002; reproduced by permission of GL Prinsloo, Agricultural Research Council, Pretoria, SA).

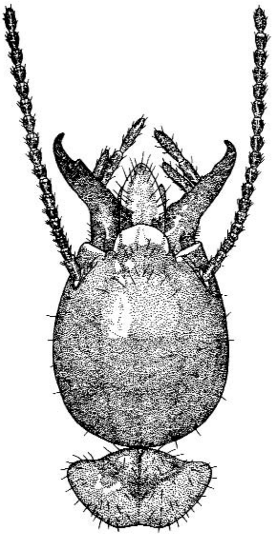


Figure 6-26. Dorsal view of head and pronotum of soldier of *Odontotermes latericius* (Termitidae). (From Uys 2000).

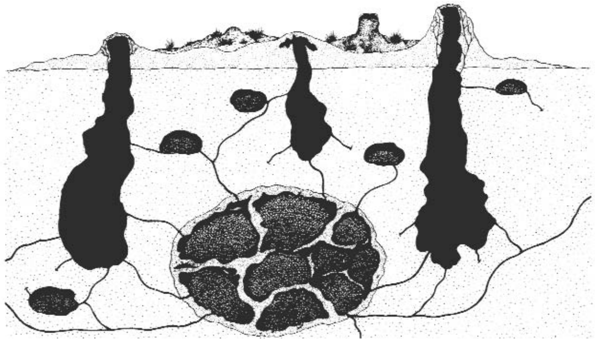


Figure 6-27. Transverse section through nest of *Odontotermes latericius* (Termitidae), showing chimneys. (From Uys 2002; reproduced by permission of GL Prinsloo, Agricultural Research Council, Pretoria, SA).

structural damage. Unlike *O. badius*, the shallow nests of this termite are equipped with chimneys of clay around wide airshafts (Figure 6-27). Their earthen runs are commonly seen on *Commiphora* spp. (Kemp 1955).

At least another 14 species of *Odontotermes* occur in Tanzania. They attack mature, often ornamental trees, as evidenced by earthen runways on the trunks through which they reach wounds and dead branches, but nursery and young trees can also be attacked.

Pseudacanthotermes (=Acanthotermes) is an afrotropical endemic genus with eight species widely distributed in the woodlands of Africa. At least two species, *P. militaris* Hagen and *P. (=Acanthotermes) spiniger* Sjöst., occur in Tanzania (Harris 1940b).

The prothorax of soldiers of these middle-sized termites has two spines on the anterior margin. In German East Africa, *P. militaris* (Figure 6-28) attacked sound wood of tapped rubber trees at Nyussi, killing 10 % (Morstatt 1913b). In Zambia, attacks on both young and mature plantation trees in the 1d pattern are common (Selander and Bubala 1983). Reproductives of this termite are widely appreciated for food (Harris 1940a).

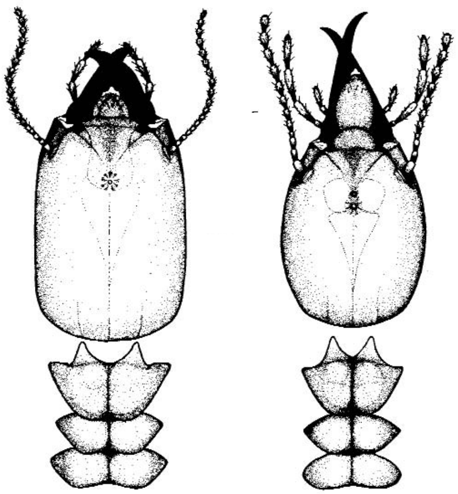


Figure 6-28. Dorsal view of head and pronotum of major (left) and minor soldier of *Pseudacanthotermes militaris* (Termitidae). (From Uys 2002; reproduced by permission of GL Prinsloo, Agricultural Research Council, Pretoria, SA).

Macrotermitinae of Lesser Significance in Forestry. In addition to the preceding “big 5”, several other genera of Macrotermitinae, including *Allodontotermes, Protermes, Sphaerotermes* and *Synacanthotermes,* occur in Tanzania. They form a significant part of the soil fauna of tropical Africa and two genera include species that cause damage to trees and wood.

The three species of *Allodontotermes* are essentially southern African but reach into East Africa. They have cryptic and diffuse nesting habits. In Zambia, they count among the ten most important genera of higher termite pests in plantations, attacking newly planted to mature trees in the 6-21a, c, e and g patterns (Selander and Bubala 1983). *A. morogorensis* Harris, an earth-nesting termite, causes damage to various trees in East Africa and also attacked wood in Shinyanga (Kemp 1951; Gardner 1957a). These termites often build sheet-like rather than tubular tunnels over tree bark.

Three species of *Synacanthotermes* occur in Africa, of which *S. zanzibariensis* Sjöst. is the principal one. These termites live in stumps and clove timber and build earthen runs. In Zambia they were among the 10 most important higher termite pests in plantations, attacking newly planted stock to mature trees in the 6-21b, e, g patterns (Selander and Bubala 1983).

Subfamily Apicotermitinae. These soldierless termites consist of 108 species of soil-feeding termites endemic to Africa (Kambhampati and Eggleton 2000). Both biologically and taxonomically, they are the most enigmatic group of termites. Most live in diffuse underground gallery systems, and only a few build nests. The species group “*Anoplotermes*” consists of termites concentrated in southern Africa (Sands 1972). In Zambia, some were implicated in attacks on eucalypts of various ages and sizes in the 6-21c pattern, resulting in hollow roots (Selander and Bubala 1983). The majority is

likely to be of greater ecological significance than as forest pests. Some were previously included in a separate subfamily, the Amitermitinae.

Subfamily Termitinae. Because of the great diversity of their habits, these termites do not carry a common name. There are 272 species in tropical Africa (Kambhampati and Eggleton 2000). Many build small to larger mounds, and they generally occur in soil, litter, animal dung and broken branches. Some are guest termites in the nests of other Isoptera.

The *Cubitermes* group is an endemic African soil-feeding cluster of termites, including Tanzanian representatives (*Basidentitermes, Crenetermes, Cubitermes, Euchilotermes, Noditermes* and *Procubitermes).* Most form amorphous subterranean colony centers with often strikingly high biomass densities (Eggleton 2000).

The *Termes* group has typically soldiers with asymmetrical mandibles. Some are soil feeders, others prefer wood. Tanzania has species in at least the genera *Angulitermes, Pericapritermes, Promirotermes* and *Termes.*

The *Amitermes* group, including the wood feeding *Amitermes* and *Microcerotermes,* is predominantly pantropical. In Zambia, *Amitermes (=Hamitermes)* were among the ten most important higher termites damaging plantation trees. *Amitermes* spp. attack newly planted eucalypts to mature trees and coppice crops in the a, c, e, g patterns (Selander and Bubala 1983).The black mound termites *A. hastatus* Haviland are a common, very small species. Their black, domed mounds (Figure 6-29), about 35 cm high and 50 cm wide at the base, are a common sight in many parts of sub-Saharan Africa. These termites are found in dead, sound wood and also forage humus (Skaife 1979). Three other species of *Amitermes* are found in dead wood or litter in Tanzania.

Figure 6-29. Vertical section through nest of *Amitermes* sp. (Termitidae). (From Uys 2002; reproduced by permission of GL Prinsloo, Agricultural Research Council, Pretoria, SA).

Microcerotermes spp. feed mostly on dead trees and dry wood, but also attack seedlings and young trees at the collar or root exterior in the 6-21a,b patterns (Selander and Bubala 1983). This is a widely distributed pantropical genus that builds carton nests made from feces containing lignin, cellulose and other plant matter. Their small, domed mounds are subterranean or concealed in other termite colonies. Soldiers of *Microcerotermes* are easily recognized by their long, rectangular head capsules and mandibles with incurved tips and inner serrations (Figure 6-30). Their antennae have 12-15 segments. *M. parvus* Haviland may be the best known of the eight species in this genus in Tanzania (Harris 1961). This is a small mound builder widely spread in dry woodlands from West through East to South

Africa. It attacks dead trees as well as wounds in young and mature trees, including *Leucaena glauca*. This was one of the four main species responsible for attacking wood in an experiment in Shinyanga (Kemp 1951).

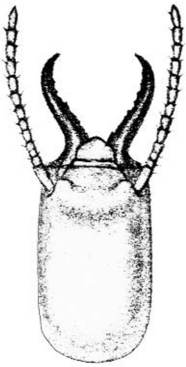


Figure 6-30. Heads of major soldier of *Microcerotermes parvus* (Termitidae). (From Sjöstedt 1926).

Subfamily Nasutitermitinae. The so-called nasutiform termites *(Coarctotermes, Grallatotermes, Nasutitermes* and *Trinervitermes)* occur throughout the tropics, and there are 601 species in the Afrotropics alone (Kambhampati and Eggleton 2000). These termites have soldiers with pear-shaped heads, characterized by a snout-like extension (nasus) and greatly reduced mandibles (Figure 6-31). Many species construct spherical carton nests on tree trunks, others build small dome-shaped mounds and still others are subterranean. Some *Nasutitermes*, the most species-diverse genus in the higher termites, are minor structural pests.

3.6. Termite Management

Traditionally, different physical, chemical or silvicultural methods have been employed to address termite problems in structural or field contexts (Harris 1943, 1971; Wilkinson 1965; Pearce 1998).

3.6.1. Structural Damage

Prevention of termite damage to structures ideally envisions the use of naturally resistant wood. At one time or other, both the German and British colonial governments promoted the search for and evaluation of tree species that would hold up against attack by termites and other destructive agents. Ultimately, the list of resistant commercial timbers in tropical Africa or East Africa (Harris 1961, 1971) turned out to be fairly small, including *Afzelia quanzensis, Brachylaena hutchinsii, Chlorophora excelsa, Diospyros* spp., *Erythrophleum guineense, Olea welwitschii, Piptadenia africana* and *Pterocarpus angolensis*. Other species were recommended on a more qualified basis, including the mangrove *Rhizophora mucronata*, which is supposedly perishable in ground contact but highly resistant used in roofs (Campbell 1974). Wigg (1946) offered a provisional list of some 285 species of East African timbers proven or believed to resist destructive agencies, including termites

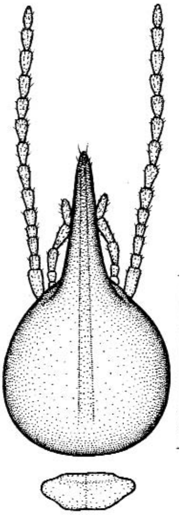


Figure 6-31. Dorsal view of head and pronotum of soldier of *Nasutitermes kempae* (Termitidae). (From: Uys 2002, reproduced by permission of GL Prinsloo, Agricultural Research Council, Pretoria, SA).

and made recommendations for the use of certain species in various regions. He cautioned, however, against "undue optimism about the natural resistance of any timber", given a number of variables. For instance, *Acacia fischeri,* used by the Sukuma for poles, is only resistant after water seasoning. As well, based on experiments conducted in Shinyanga, Kemp (1951) listed six species of timbers as "readily attacked", 18 as " moderately attacked" and five as "almost unattacked". The latter include *Ormocarpum trichocarpum, Strychnos heterodoxa, Dichrostachys glomerata, Acacia rovumae* and *Abrus schimperi.* Among exotic species, *Tectona grandis* and *Camphora* spp. are considered termite-resistant (Schnee 1920).

Experiments with DDT, BHC, sodium arsenite, mercuric chloride and creosote gave mixed and qualified results (Morstatt 1912b; Wigg 1946; Harris 1948, 1949, 1952). Other recommendations for structural termite control or prevention include bait laced with pesticides or molting inhibitors, the use of non-wood building materials, pressure-treating wood with copper-chromium-arsenate (CCA), and the establishment of shields and other physical barriers on wooden structures. Most of these solutions have limited prospects for wide-scale use in Tanzania. Conscientious application of oil-based paint does, however, promise some protection, if the ends or joints of timber, where termites notoriously attack, are fully covered. According to Cowie et al. (1989), chemical control of drywood termites provides only temporary relief, as wood is likely to be attacked again. Simply standing the legs of chairs and tables in water or oil may be a somewhat awkward solution to keep termites at bay, but it worked for the recent Tendaguru dinosaur expeditionary force (Maier 2003).

3.6.2. Field Damage

In German colonial days, calomel with sugar mixed into the soil at the time of planting was considered effective in protecting seedlings, as well as the digging out of queen termites (Morstatt 1913b). Prompted by routine complications with termites in Tanzanian tree nurseries and dryland plantations, relevant experience with pesticides was summarized (Parry 1959; Wilkinson 1964; Reddy 1975). This involved the thorough mixing of potting soil with dust or wettable powder of aldrin or dieldrin, followed by a second dose before outplanting. When deep planting precluded nursery treatment, the same pesticides were used in the field, although at different rates. Insecticidal dust was either mixed with soil in the planting holes at planting time, or it was sprinkled below and around the roots and stems. Alternatively, wettable powder mixed with water was applied to the root region at planting. Both pesticides gave 5-6 years protection. Important in this procedure was establishing a complete chemical barrier around the roots and on the ground surface around the tree. Cowie et al. (1989) reported other approaches, such as the blowing up of termite nests or the use of cyclodienes and other persistent pesticides as mound poisons or root barriers against termites attacking seedlings.

Based on concerns for the environment, pesticides began to be restricted or banned by certain governments or donors since the 1970s. As a result, this effective

chemical approach was no longer feasible, and the search for alternatives, including biorational, biological, cultural and integrated controls accelerated (Weidner 1988; Cowie et al. 1989; Curry 1965a; Wood and Pearce 1991). However, since controlled release formulations of more acceptable, modern insecticides tend to be expensive, reliance on using termite-resistant seedlings continues to be a better solution for dry areas of Africa. Harris (1961) and Brown (1965) recommended *Acacia* spp., *Albizia lebbeck*, *Callitris*, *Cassia siamea*, *Casuarina*, *Gmelina*, *Jacaranda*, *Maesopsis eminii* and *Tectona grandis* for such sites, in conjunction with avoidance of susceptible exotic tree species. Supplemental measures to enhance the vigor of seedlings by carefully matching trees with proper sites in combination with post-planting care, i.e., weeding, mulching, and fertilizing, are also advised. Another cultural approach encourages planting of about 20-30% more seedlings than are needed, and to provide alternate foods for termites.

Recently, Douglas (1991) outlined alternative home-made termite controls for agroforestry. These included the use of Gondal fluid, a concoction developed in India, including 100 g gum, 200 g asafetida, 200 g aloes and 80 g castor cake. As well, the use of poison baits, such as 25 g Paris green, 100 g flour, and 80 g sugar mixed into a stiff dough and, alternatively, thick flour dough mixed with 50 g borax and 100 g sugar were encouraged. A lime/sulfur mix forked into soil also supposedly discourages termites.

CHAPTER 7

FLOWER, FRUIT AND SEED FEEDERS

1. INTRODUCTION

In the 1970s, Tanzania launched national tree planting campaigns to rehabilitate degraded sites and promote community forestry. This created high demand for tree seeds for various uses, but the scope of the task was such that demand soon outpaced the supply (Shehaghilo 1987). As a result, the National Tree Seed Program (NTSP) was initiated in 1989. In conjunction with governmental reforms in the 1990s, this program was subsequently transformed into the Tanzania Tree Seed Agency (TTSA), with branches in Morogoro, Lushoto and Iringa. This agency harvests about 10 tons of seeds per year from 150 tree species and supplies them to more than 500 customers. Based on recent evidence of the vulnerability of some exotic plantation species and legal mandates for the protection and restoration of threatened species, the emphasis is now on indigenous trees. These often have numerous traditional uses, are well adapted to local environments and, with increasing scarcity, have become more highly valued. Along with studying the biology, storage behavior and production technology of indigenous tree seeds, the TTSA still handles some improved exotic tree seeds and supplies other tree propagules.

1.1. Damaging Agents

Most orthodox seeds may be subject to lengthy storage and thus are particularly vulnerable to pests, as these can build up in seed lots. However, irregular fruiting of certain trees often makes seed storage inevitable.

Birds, mammals, insects, fungi and bacteria account for damage to or total destruction of flowering as well as fruiting stages of trees and thus complicate seed orchard management, seed storage, the nursery business and silvicultural attempts at natural regeneration. While flowers and developing fruits are delicate, succulent and well supplied with minerals, seeds are generally low in water and mineral contents, but rich in organic substances and high in caloric value.

Insects are probably responsible for the most serious losses in the greatest number of species, but unlike in West Africa where more detail is available (Wagner et al. 1991), published information on their role in Tanzania is very limited. Seeds of virtually all forest trees are subject to insect attack, while still attached to the tree, after dropping, or in storage. Insects consume tree seeds either from the outside or by entering the seed as borers. Seed production can also be impacted by other pest organisms, including defoliators and sapsuckers that affect general tree health. For instance, after the cypress aphid surfaced in East Africa, local cypress seed orchards suffered substantial losses in seed production (Obiri et al. 1994).

The most important forest tree fruit and seed destroyers in East Africa include larval Coleoptera and both immature and adult Hemiptera, while the most significant flower damage is attributable to certain adult Coleoptera. Succulent fruits are also subject to attack by many Hemiptera, especially aphids and scale insects (Figure 4-6), but these attack any succulent tissue opportunistically, while the other insects mentioned tend to be fruit, seed or flower specialists. In other parts of the world, certain Diptera, Hymenoptera and Lepidoptera are important tree seed and fruit pests, but little seems to be known about their potential role in East Africa. Most knowledge has accumulated about insects attacking the fruity pulp of trees grown primarily for their fruit (Hill 1983), but these will not be considered in this chapter, as they are mostly in the horticultural or agricultural domain.

1.2. Insects Aiding Germination

Although seed predators destroy many seeds, some also contribute to successful seed dispersal or germination. Damage by any agent is only significant if cotyledons, the hypocotyls or the radicle of the seed are affected. For instance, the hard seeds of many dry area species of legumes suffer serious damage from bruchid larvae (Armitage et al. 1980). In species such as *Acacia tortilis*, *Erythrina abyssinica* and *Faidherbia albida* these beetles may, however, contribute to the breaking of the seed dormancy and, in the presence of sufficient moisture, seeds often germinate fast enough to avoid being killed by the developing larvae (Msanga 1998; Schmidt 1998). One method to increase seed germination in *Pterocarpus angolensis* is to allow termites to eat the tough wings and bristles of the fruit (Msanga 1998). Although a slow process, termites can also help in the extraction of *Prosopis* seed, by eating the pods while leaving the seed unharmed (Albrecht 1993).

1.3. Management

Prevention and control of tree seed insects (Schmidt 1998) largely copies experience gained with stored product pests, which are often the same or related insects. Recommendations include the isolation of seed orchards from natural forests, the timely collection of seeds, tight and proper storage of seeds or the use of various repellents, ideally combined in integrated programs. To detect existing infestations,

seed tests routinely rely on verification of exit holes, enlarged seeds and, where available, X-ray photography.

There are two aspects to timely seed collection, i.e., the year of collection and the time of year. Following poor seed years, infestation rates are often low in good seed years, while infestation rates after good seed years are often high (Wagner et al. 1991). Overall, early collection of seed when infestation levels are still low, followed by immediate dusting with pesticide and subsequent cold storage, are considered best to prevent infestation (Armitage et al. 1980). Insecticides are recommended routinely for the storage of legume seed (*Acacia*, *Delonix*, *Faidherbia albida* and *Newtonia buchaninii*), as well as that of *Schinus molle* (Albrecht 1993). In Zambia, seed of exotic pines and eucalypts is generally free from insect attack while still in the field, but once in storage it can be affected by any number of non-selective seed feeders, mostly beetles (Shakacite 1987).

Most East African orthodox seed can be stored in controlled atmospheres, i.e., airtight, dry and cool environments or at room temperature (Albrecht 1993). Storage at less than 8-9% moisture content much reduces insect and fungal activity, while storage is considered entirely safe at 4-8%. Some air exchange is required for storage of recalcitrant seed.

Fumigation with carbon dioxide, or storage in conjunction with traditional botanical grain protectants or repellents, including neem oil at 5-10 ml per kg seed, pyrethrum, pepper chilis, custard apple seed powder, pepper, onion oil or the dried and powdered leaves of utupa (*Tephrosia vogelii*), a leguminous shrub containing rotenone, provide other options (Schmidt 1998).

Pheromones and light traps may eventually become feasible and operational in conjunction with commercial seed production in seed orchards although appropriate preventive measures frequently preclude the need for such.

2. FLOWER-, FRUIT- AND SEED-FEEDING BEETLES

2.1. Anobiidae: Death-watch Beetles; Woodworms

This is a family of about 1,500 species of small, less than 6 mm long beetles with 3-segmented antennal clubs. The larvae are mostly associated with boring in the wood of dead, dry trees already afflicted with a degree of fungal decay, or in structural wood and household commodities. At least four wood-boring and two seed-boring species occur in East Africa (Gardner 1957a). Although the common furniture beetle *Anobium punctatum* (de Geer) is known in other parts of Africa (Peake 1949; Scholtz and Holm 1985), attacks in structural wood and furniture by this most notorious of wood-boring anobiids have not yet been documented in East Africa (Gardner 1957b).

Most anobiids are pale brown to black and vary from elongate to oval. The head is usually hidden under the pronotum, and the short legs are embedded in grooves on

the underside. Depending on species, the about 100 eggs are laid on wood or seed, from which the larvae bore round tunnels into the substrate. The slightly curved, white grubs have short thoracic legs. Pupae are found just under the surface of whatever substrate the larvae develop in.

2.1.1. Stegobium paniceum (L.): *Drugstore or Biscuit Beetle*

This beetle has the reputation of eating anything but cast iron. In nature it is found living in beehives, feeding on pollen. It has, however, become a serious cosmopolitan pest of processed and packed food, museum specimens, spices, drugs, chocolate etc. In Kenya it was also found in stored seed of *Pinus palustris* and *P. occidentalis*. The brown to reddish-brown, 2.25-3.5 mm long beetles (Figure 7-1) have a three-segmented antennal club and the elytra are marked by rows of pits. Larval development takes 4-20 weeks. Pupae are contained in a cocoon and take 13-65 days to develop into adults.

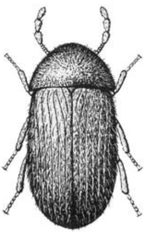


Figure 7-1. The drugstore beetle, *Stegobium paniceum* (Anobiidae), a cosmopolitan pest of organic substances including tree seed. (Reproduced by permission of Division of Plant Industry, Florida).

2.1.2. Lasioderma serricorne (F.): *Cigarette or Tobacco Beetle*

This beetle (Figure 7-2) is another cosmopolitan pest of stored products. In color and size it resembles the drugstore beetle but is wider, its antennae are serrated and it lacks elytral striation (Hill 1983). This insect was found in seeds of *Faidherbia albida* and *Dalbergia melanoxylon* in Tanzania (Gardner 1957a). The eggs develop in 6-10 days. The grubs have four instars and take 17-30 days to reach the pupal stage. After 3-10 days the beetles hatch and after a 3-10 day pre-emergence period, they surface. They only live for 2-6 days, drinking but not feeding during that period. Overall development takes from 26-90 days. In warm climates there may be 5 or 6 overlapping generations.

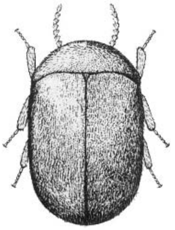


Figure 7-2. The cigarette beetle, *Lasioderma serricorne* (Anobiidae), another cosmopolitan pest of stored products including tree seed. (Reproduced by permission of Division of Plant Industry, Florida).

2.2. Anthribidae: Fungus Weevils, Broad-nosed Weevils

This family includes about 3,000 species, mostly in the tropics. Some taxonomists consider them to belong to the Curculionidae. Most larvae bore in seasoned or decayed wood, with a preference for the latter (Peringuey 1887; Löyttyniemi and Löyttyniemi 1987b). Others develop in fungi or various plant tissues.

The adults eat fungi, pollen, bark and even scale insects. One species attacks seeds.

The oblong beetles, between 3-50 mm long, are covered with patterns of white or dark scales or hairs (Figure 7-3). The head extends into a short, broad snout and the antennae are mostly long and slender, occasionally ending with a 3-segmented club. The larvae are white, c-shaped, cylindrical grubs often with short, two-segmented legs. The biology of anthribids is largely unknown. They fly mostly during the rains, and most are univoltine (Löyttyniemi and Löyttyniemi 1987b).

Of the many species in Africa, a few are minor pests of timber during prolonged storage: however, the following beetle is of some concern as a destroyer of seeds.

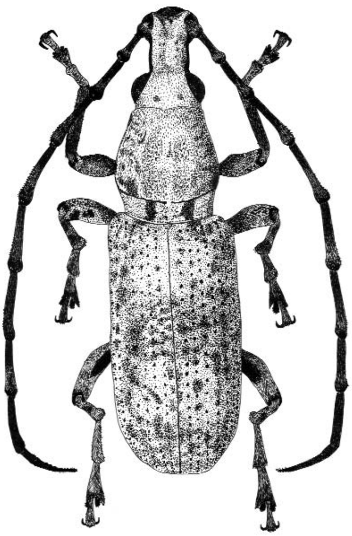


Figure 7-3. This particular species is not a seed feeder but represents a typical broad-nosed weevil (Anthribidae). (B. Anderson).

2.2.1. Araecerus fasciculatus (De Geer)*: Coffee-Bean Weevil, Cocoa Weevil*

This beetle probably originated in India, but is now of pantropical distribution (Booth et al. 1990; Rees 2004). It is a serious pest of stored dried fruits, spices, tubers, coffee and cocoa beans, but also attacks other seeds, including those of tree legumes such as *Acacia* and *Cassia*. The damage is very similar to that of bruchids (Ashman 1962). Seeds below 8% moisture content are not attacked (Rees 2004).

The beetles are 3-8 mm long, dark or grey brown with patches of light-colored setae giving them a mottled appearance (Booth et al. 1990). The three apical segments of the antennae form a loose club. They usually lay eggs in legume pods that are nearly ripe, and the 5.5-6 mm long larvae bore into the seeds, but they have also been retrieved from the branch wood of ginger (Möbius 1898). Larvae are scarabiform, hairy grubs with rudimentary legs (Rees 2004). Pupation occurs in a cell near the seed surface (Morstatt 1912e).

2.3. Bruchidae: Seed Beetles, Pea or Bean Weevils

Worldwide there are about 1,300 species of bruchids. They were long considered closely related to the weevils and thus were often referred to as such. Some taxonomists now include them with the Chrysomelidae, as the subfamily Bruchinae (Rees 2004). Their larvae feed exclusively on cotyledons of a wide variety of seeds, especially legumes, palms and *Combretum*, making them a significant threat to tree regeneration in the field, and major pests in seed storage. While infestation levels as high as 99.6% have been recorded (Lamprey et al. 1974), they generally vary from

0-80%, tending to be higher in years with poor seed crops, at low tree densities and in indehiscent species of *Acacia*, as opposed to dehiscent ones (Ernst et al. 1990b). With few exceptions, only one larva develops in one seed in most tree species. However, even at high population levels, regeneration of hosts is not as much impaired by seed predation, as it is by precipitation (Ernst et al. 1990a). Under storage conditions, losses can be significant though, if the beetles are not controlled.

2.3.1. Host Relationships

Some seed weevils are fairly host-specific because they can deal with toxic alkaloids and uncommon amino acids, while for others food specificity is low (Janzen 1972; Pellew and Southgate 1984; Ernst et al. 1990a, b; Tonder 1985). Also, not all species of *Acacia* are affected to the same degree by bruchids, and some appear to be unacceptable as hosts for these beetles (Ross 1979). In Uganda, for instance, bruchids promote early germination and seedling establishment *of Acacia sieberiana*, while they significantly reduce the germination and seedling establishment of *Acacia gerrardii* (Mucunguzi 1995). The former of these two acacias has tough, woody, thick, indehiscent pods that are habitually ingested by mammals, during which process any bruchids in the seeds are killed. On the other hand, *A. gerrardii* has dehiscent fruit and thus escapes ingestion by mammals, so many bruchids survive to destroy the seeds. Some of the more host-specific bruchids are used for biological control of weedy legumes such as *Leucaena leucocephala* and certain species of *Acacia* (Schmidt 1998).

2.3.2. Description

The beetles are mostly robust, short, 1-30 mm long, oval, compact, dull brown or black and mottled. The antennae may be different in the two sexes. Mature larvae are white, short, broad and have a small, retracted head and very short legs (Booth et al. 1990; Rees 2004).

2.3.3. Life History

The life cycle of bruchids on pods of *Prosopis* (Figure 7-4) may serve as a model for most beetles in this family (Johnson 1983). Eggs are laid in or on the green pod in the spring, shortly after the flowers drop (Ross 1979). The larvae hatch a few weeks later and penetrate young seeds, in which they feed. They pupate either in the fruit or below ground level. The adults emerge through a round hole in the seed coat, unless the larvae or prepupae remain dormant inside, or the seeds are eaten by mammals before the beetles have had a chance to hatch. Shortly after emerging, some adults in certain species may lay eggs on remaining seed, allowing production of further generations of bruchids in the same batch of dry seeds under a tree. Infested seeds remain viable only if the embryo is undamaged or if parts of the cotyledons have survived. However, in the small number of infested seeds that do remain viable, the bruchid exit holes greatly increase the permeability of the seed coats to water and thus facilitate more rapid germination (Ross 1979). Beetles developing in green seedpods have

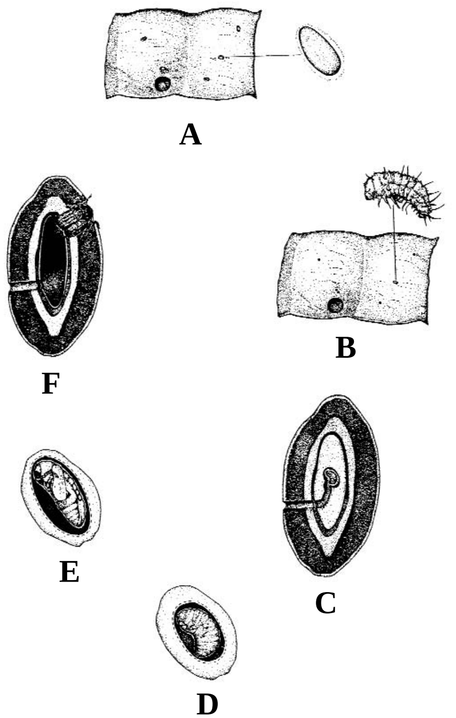


Figure 7-4. Generalized composite life cycle of bruchids (Bruchidae) on seed pods of *Prosopis*. A. Eggs glued onto seed pod. B. First instar larva (enlarged) and its entry hole in the seed pod wall. C. Cross section of pod and seed showing the tunnel dug by the first instar larva. D. Later instar larva occupying the cavity it has excavated in the seed. E. Pupa inside larval feeding chamber. F. Adult emerging through hole prepared by last instar larva. (From Johnson 1983; reproduced by permission of the Food and Agriculture Organization of the United Nations).

usually only one generation per year, while those attacking dry pods and seeds may have continuous generations and thus can build up dangerously in seed stores.

2.3.4. Major Forest Bruchids

While presumably quite a number of species of bruchids occur in East Africa, few specifics are available. Often records exhaust themselves with host references, most commonly species of *Acacia*, *Bauhinia*, *Erythrina* and *Tamarindus* (Gardner 1957a). *Trichilia roka (=emetica*) in Tanzania is also said to suffer seed losses from an unidentified "weevil" (Mugasha 1978). Relatively more is known about the following seed weevils, as they are general seed storage pests.

Bruchidius (=Bruchus) spadiceus (Fahr.) In Africa, beetles in this genus commonly attack legumes and especially *Acacia*. They are rarely seen, as they are cryptic, small and nocturnal. Some *Bruchidius* spp. have wide host ranges, while others are more selective. In Botswana, seed predation on tree legumes varied strongly between and within species from 9% to more than 80%, and developmental periods for different species on different hosts varied from 39 to about 100 days (Ernst et al. 1990b).

In Tanzania, research with *B. spadiceus* unraveled a compelling story in ecology and natural history, involving a triangular relationship between this beetle, *Acacia*

tortilis spirocarpa and large mammals (Lamprey et al. 1974; Pellew and Southgate 1984). The potential impact of *B. spadiceus* on this particular acacia, the dominant tree of the central woodlands in the Serengeti, is considerable, as shown by infestation levels averaging 73.6 % of seeds. Seeds occupied by one of these beetles are invariably killed unless they pass through one of the large herbivores (Lamprey et al. 1974).

Eggs are laid on developing seedpods some 30-60 days after the tree flowers. The larvae enter the seed to feed and eventually pupate. After approximately 150 days, the pod drops. If uninterrupted, the beetles usually continue to develop and emerge through a circular exit hole from the pod, about 15-30 days after it falls. Such seeds are usually sterile. Interruption occurs when the pods are ingested by herbivores such as elephant and various antelopes shortly after they fall from trees. This not only aids the dissemination of acacia seed away from infestation centers, but at the same time it kills the beetles before damage to the embryo occurs, the gut juices accelerate the seed's germination, and the dung surrounding the seedling provides fertilizer. As elephant numbers in the Serengeti increased, however, many mature *A. tortilis spirocarpa* in the park were destroyed. As a result, this finely tuned and complex inter-relationship between seed production, infestation, ingestion, dissemination and germination was also disturbed. A reduction in the number of parent trees resulted in smaller seed crops, and the rate of seed parasitism dropped to an average of 8.4%.

Caryedon serratus (Olivier) *(=Bruchus s., C. gonagra):* The groundnut seed beetle is of Asian origin, but now occurs in many tropical and sub-tropical regions. It is well established in West Africa, with a few recorded in East Africa (Prevett 1967).

This robust, 3.5-7.4 mm long beetle (Figure 7-5) is reddish-brown with dark, irregular markings on the elytra (Dobie et al. 1984). The wide hind femurs bear a conspicuous comb of spines. This beetle is almost always associated with the commercial production of groundnuts or *Tamarindus indica* seed, and in natural conditions with wild tree legumes including *Piliostigma*, *Bauhinia*, *Cassia* and *Acacia* (Prevett 1967; Dobie et al. 1984).

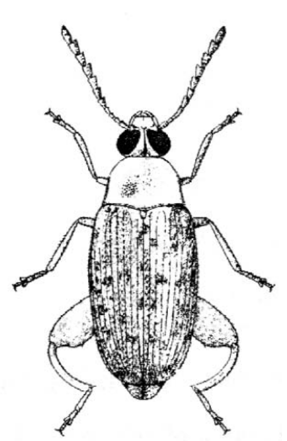


Figure 7-5. The groundnut seed beetle, *Caryedon serratus* (Bruchidae), which is almost always associated with the commerce of groundnuts and seeds of tamarind and other tree legumes. (From Dobie et al. 1984; reproduced by permission of the Natural Resources Institute of the University of Greenwich, UK).

The eggs are glued onto legume pods or seeds and the newly hatched grub bores into the seed. In Niger, when given a choice of seeds of various legumes, the beetles preferred to lay eggs on those of *T. indica* (Ali-Diallo

and Huignard 1993). Unlike most bruchids, under storage conditions the cocoon of this beetle is attached to the outside of a pod, while pupation in the field takes place in the soil (Schmidt 1998). Under optimum conditions, the development period is 40-41 days and adults live 20-30 days. In stored legume seeds, *Caryedon* breeds successively and thus produces as many generations as the food supply allows, often destroying entire stocks. Populations in the field tend to decline with the onset of rains (Pierre and Huignard 1993).

2.4. Cerambycidae (Lamiinae): Seed-Feeding Longhorn Beetles

With a length of 5-11 mm, most of these beetles are dwarfs among their kin. Knowledge about them, other than that the larvae develop in seeds and that the beetles are attracted to light, is scant.

2.4.1. Enaretta castelnaudi Th.

This beetle from West, East and southern Africa, represents a genus that is considered among the dominant seed predators in southern Africa (Ernst et al. 1990a). *E. castelnaudi* attacks the pods of *Acacia albida*, *A. fulvida*, *A. hebeclada* and *A. stolonifera* to feed on the seeds (Gardner 1957a; Duffy 1957). Adults are about 10 mm long and covered with a grayish pubescence with scattered darker punctures. At least two other species in this genus occur in Tanzania (Forchhammer and Breuning 1986).

2.4.2. Sophronica spp.

At least 20 species of *Sophronica* exist in Tanzania, including five relatively new to science (Forchhammer and Breuning 1986). *S. bicoloricornis* Pic. and *S. calceata* Chevr. are found in pods of *Acacia albida*, while *S. calceata* also occurs in fruits of *Calodendrum* (Gardner 1957a; Duffy 1980). Some species of *Sophronica* are reported in woody shrubs, and one is a pest in coffee beans (Gardner 1957a; Skaife 1979).

2.5. Curculionidae: Seed-feeding Weevils

Among three seed-feeding weevils reported to occur in East Africa (Gardner 1957a), only the tamarind pod borer *Sitophilus (=Calandra tamarindi) linearis* Herbst is of some importance, and its life history is known as a result of a detailed investigation in Florida (Cotton 1920). This weevil is native to India, but has become a notorious pest of stored seed of tamarind and some other large-seeded legumes throughout the tropics where entire crops have been destroyed. The weevil has numerous synonyms.

This weevil breeds throughout the year. The females bore through the pulp into a seed, where they dig a cavity and over 1-2 weeks lay 12-50 minute eggs in individual niches along the side of the cavity. The total number of eggs amounts to as many as 183. The eggs hatch after three days and the larvae bore into the seed, gradually

turning the contents to powder. The larvae (Figure 7-6) are typical legless grubs, 2.5-3.5 mm long. After 12-14 days of development involving four larval instars, they build pupal cells within the seed, lined with frass and borings cemented together. After spending one day as a prepupa and seven days in the pupa stage, adults hatch but do not leave the seed until a few days later.

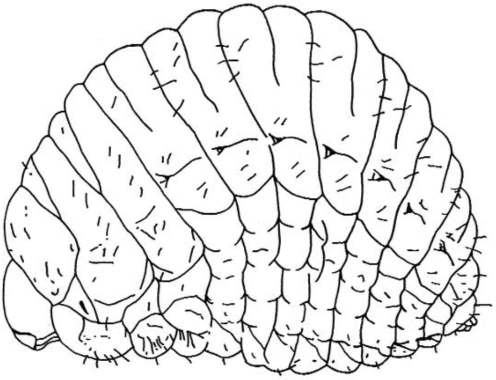


Figure 7-6. Larva of the tamarind pod borer, *Sitophilus linearis* (Curculionidae), a pest of tamarind and other large-seeded legumes. (B. Anderson).

2.6. Meloidae (=Cantharidae): Blister, Oil or Flower Beetles

Over 2,500 species of blister beetles exist worldwide, many in Africa. Some affect agricultural crops, but a few are of interest as tree pests or as antagonists of certain pests of trees or wood. Blister beetles are often seen swarming on flowering trees or other plants. As they contain cantharidin, which blisters skin and may be lethal if ingested, they must be handled carefully. Witch doctors are said to have made sinister use of this poison (Skaife 1979).

2.6.1. Description and Life History

Blister beetles are from 10-50 mm long. Because of the narrow first thoracic segment and a distinct neck, the head appears relatively large. They are soft-bodied, including the wing covers. Conspicuous bands of red, yellow or orange function as warning colors. Beetles in this family can be readily identified by five tarsal segments in each of the front and middle legs, but only four in the hind legs.

The biology of blister beetles is often complex. The larvae parasitize grasshoppers or solitary bees and exhibit hypermetamorphosis, i.e., they have dissimilar larval instars and a false pupa (Skaife 1979). The first instar larva, called triungulin, which resembles a mini-silverfish, has well developed legs and is very active. Subsequent instars are fat, inactive grubs. Eggs of blister beetles parasitizing bees are either laid near the entrance to bees' nests or on flowers, from where the larva hitches a ride into a bee's nest.

2.6.2. Major Blister Beetles

Only two genera, of blister beetles, species of *Mylabris* and *Synhoria*, appear of interest to forestry in Tanzania, one as a flower pest, and both as natural control agents of certain forest pests. *Synhoria* is discussed in chapter 5 in conjunction with its hosts, the carpenter bees.

Mylabris spp. F.*: Banded Blister Beetles*. These beetles are very common throughout sub-Saharan Africa and tropical Asia. At least 19 species are found in Tanzania (Le Pelley 1959). Most are of greater concern to agriculture than forestry. Adults of various species of *Mylabris* often congregate on *A. tortilis, Dichrostachys cinerea* and *Leucaena leucocephala,* as well as on various fruit trees and numerous ornamentals or agricultural crops. By feeding on flowers, pollen and sometimes leaves, they have the potential to become sporadic pests, as they prevent or reduce seed production. Based on the intimate arrangement of agricultural crop legumes with tree legumes in agroforestry, it is expected that these beetles may become more significant pests in the future (Shanker and Solanki 2002). However, since the larvae of *Mylabris* also prey on grasshopper eggs, they may in many circumstances be more beneficial than damaging.

The adults (Figure 7-7; Plates 52, 53) are large (10-35 mm), usually black beetles, often with broad red or yellow bands or spots (Booth et al. 1990). The head, pronotum and the base of the front wings are densely pubescent. The beetles are sluggish while on foot, but fly strongly. When disturbed, they ooze an acrid, yellow liquid containing cantharidin from their leg joints, which can cause blisters on human skin.

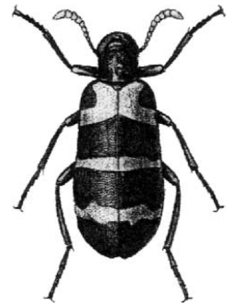


Figure 7-7. The banded blister beetle, *Mylabris amplectens* (Meloidae), like others in this genus, feeds on flowers and pollen, resulting in diminished seed crops. (From Gerstaecker 1873).

The beetles hatch at the beginning of the rains and are active for the next 3-4 months (Skaife 1979; Hill 1983). They tend to be particularly abundant following locust invasions. Females lay several batches of 20-30 fairly large, oval, white eggs into a hole dug in the ground before covering them with soil. The triungulins hatch 3-4 weeks later and frantically search for pods of grasshopper eggs, as they will die if they do not quickly connect with food. Having found an egg, they molt into the second instar larva, a sluggish, fat, white grub with short legs and begin to feed on the eggs. For the duration of the dry season, this grub molts into a resting stage or false pupa. With the arrival of warm weather it molts again into a larva that either resumes feeding on eggs or, after a short period without feeding, changes into a pupa. Adults hatch 3-4 weeks later. Blister beetles are difficult to control, as they shift from one crop plant to another (Hill 1983).

2.7. Scarabaeidae (Cetoniinae): Fruit and Flower Chafers

This group of about 3,500 mostly tropical beetles is frequently considered a separate family Cetoniidae, rather than a subfamily of the Scarabaeidae. The larvae of most are harmless scavengers in decaying matter, such as organic soil, compost, dung or rotten wood of trees and palms, and thus are of no economic concern (Vosseler

1907h; Le Pelley 1959). Adults are day-active and most are attracted to plant sap, gum, nectar, flowers, young shoots, pollen and ripe fruit (Plates 54, 55). Some fruit chafers (*Oplostomus* and *Macromoides* spp.) invade beehives, and others are partly predaceous on scale insects and aphids, presumably attracted by pollen and/or the sweetness of honey and honeydew (Scholtz and Holm 1985). Many species have the habit of assembling nightly in large numbers on roost trees. The beetles are good fliers. Unlike other beetles, they do not open their front wings during flight, but only extend the hind wings from underneath.

2.7.1. Description

Flower chafers are small to very large, robust, squarish and slightly flattened beetles. Many are brightly colored, often in spectacular, glossy metallic patterns making them collectors' items. The heads, especially of males, often carry shovel-like or hooked projections, used to fight other males. Larvae are typical white grubs. Although there are many species in Africa, their biology is little known. Aside from the collectibles discussed in chapter 9, only one genus deserves mention in a pest context.

2.7.2. Pachnoda spp.

This genus consists of hundreds of species, all in Africa (Lepesme 1947). The adults are from 20-24 mm long (Figure 7-8). They feed on fruit and flowers and are attracted to running tree sap. Several species are common pests in beehives (Hepburn and Radloff 1998). Larvae develop in manure and compost and pupate in hard oval clay cells.

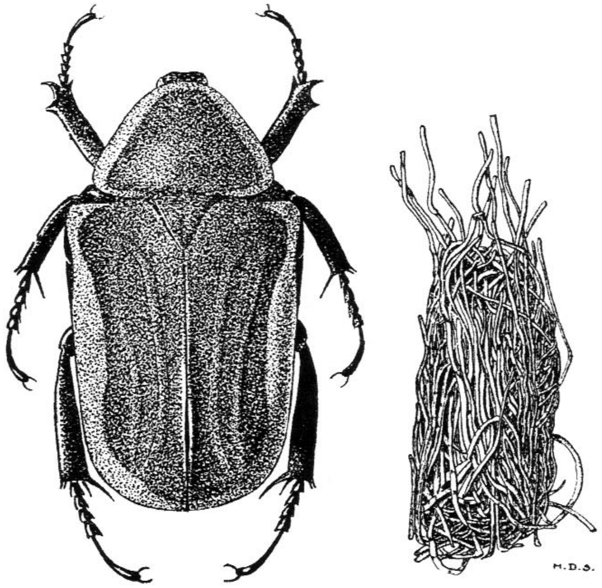


Figure 7-8. Pachnoda marginella (Scarabaeidae), a typical species in this genus with cocoon. (From Lepesme 1947).

Pachnoda ephippiata Gerst. The rose flower beetle was held responsible for low production or complete lack of *Calliandra calothyrsus* seeds, as a result of feeding on and destroying the flowers of this valuable fuel wood and fodder species in Kenya (Kaudia 1990). This beetle was originally reported on dead *Warburgia ugandensis* and also occurs on *Eriobotria japonica* and *Leucaena pulverulenta*.

Pachnoda euparypha Gerst. is a nutritional competitor of *Oryctes* (Paul 1985).

Pachnoda sinuata F. is a brown-and-yellow fruit chafer known as the rose beetle. It is common from East to South Africa, feeding on the fruits and flowers of many crops including those of trees such as mango and *Erythrina* (Le Pelley 1959). It has several forms in varying patterns of a smooth yellow and black.

Several other species of *Pachnoda* have been found to attack *Ficus thonningii*, *Acacia polyacantha*, *Acacia albida*, *Calliandra calothyrsus* and *Dombeya*, by feeding on flowers, fruits and foliage (Kaudia 1990).

2.8. Scolytidae: Seed Scolytids

As discussed in chapter 5, most scolytids are important bark and wood borers, but a few *Coccotrypes* spp.are seed specialists, including serious pests in crops such as coffee and certain minor crops.

Coccotrypes carpophagus (Hornung) is a 1.5-1.9 mm long, reddish-brown to black beetle, probably originating in Africa, but now almost pantropical (Booth et al. 1990). It breeds in a variety of fruits and seeds, especially betel nut, ivory nut and various other palm seeds. Males are deformed and wingless, smaller than the females. In palm nuts, the female beetle bores a tunnel ending with an egg chamber. The larvae do not burrow within the nut, but live in the tunnel made by the parent and feed on endosperm until they pupate in the same space. In Kerala, India, the total life cycle (Figure 7-9) takes from 22-29 days, and the beetles live for about a month (Oommen and Nair 1968).

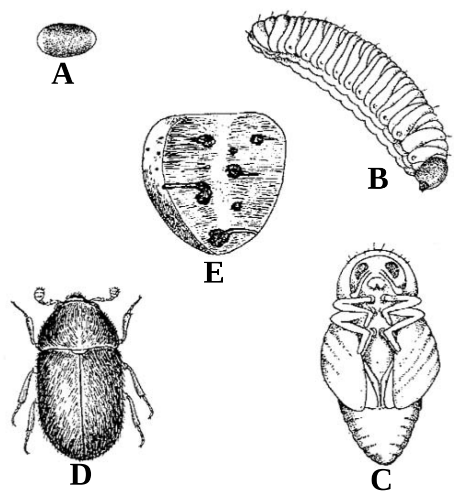


Figure 7-9. Coccotrypes carpophagus (Scolytidae). (A) egg (B) larva (C) pupa and (D) adult of this notorious borer in a variety of fruits, especially palm nuts. (E) shows a palm nut with several egg chambers. (From Oommen and Nair 1968; modified).

C. cyperi (Beeson) probably originated in South East Asia but is now almost pantropical. It breeds in cola, avocado, coffee and cocoa seeds, but also in the bark of various trees including pines (Booth et al. 1990).

C. dactyliperda F. is another feeder in the seeds of various palms, especially those of the doum palm (*Hyphaene thebaica*) (Morstatt 1913b). Buttons made of

these nuts are also infested, with possibly an entire family of the beetles inhabiting one button (Gardner 1957a). This beetle probably originated in Africa, but is now pantropical.

3. FRUIT- AND SEED-FEEDING HEMIPTERA

Many Hemiptera, especially aphids and scale insects, opportunistically feed on the immature fruits of trees, but the same insects tend to be more significant on other succulent tissues of the same hosts such as foliage and shoots. There are, however, some specialists on fruits and seeds of woody plants in East Africa that will be discussed in greater detail below.

3.1. Pyrrhocoridae: Red Bugs, Cotton Stainer Bugs

This is a small family of brightly colored, medium-sized bugs without ocelli. One pantropical genus, *Dysdercus* spp., the cotton stainer bugs, with at least 11 species in Africa, is considered the most important pest in this family (Schaefer and Panizzi 2000). Eight species have been recorded in Tanzania: *Dysdercus cardinalis* Gerst., *D. fasciatus* Sign., *D. festivus* Gerst., *D. intermedius* Dist., D. *orientalis* Schout., *D. pretiosus* Dist., *D. nigrofasciatus* Stål, and *D. superstitiosus* (F.) (Freeman 1947; Couilloud 1989), the more important ones being depicted in Figures 7-10 and 7-11.

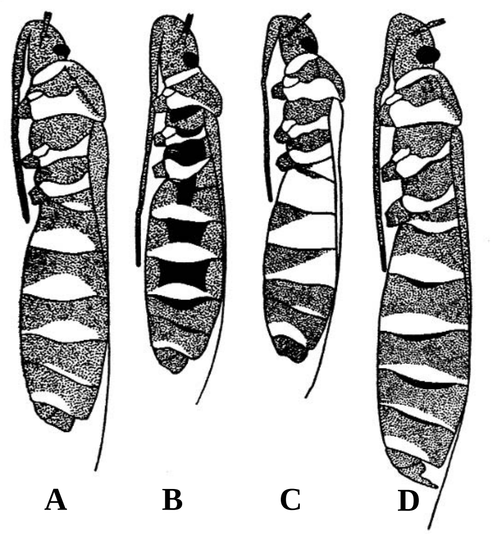


Figure 7-10. Partial lateral views of (A) *Dysdercus superstititosus* (B) *D. fasciatus* (C) *D. cardinalis* and (D) *D. intermedius*, common cotton stainer bugs (Pyrrhocoridae) in Tanzania. (From Freeman 1947; reproduced by permission of The Royal Entomological Society of London).

Concerns about this genus primarily stem from the economic impact on cotton crops (Schmutterer 1969; Hill 1983) although main hosts in Africa are trees in the family Malvales (*Adansonia*, *Bombax*, *Ceiba*, *Dombeya* and *Sterculia*, among others). In general, the larger species of stainer bugs are strongly arboreal (Schuh and Slater 1995), but seasonal shifts from trees to malvaceous shrubs and herbs and v.v. are common, reflecting successions of ripe seeds on which these bugs depend (Schmutterer 1969; Kasule 1985). Besides destroying seeds and fruits, they also vector a fungus that stains the cotton (kapok) associated with ripe malvaceous

fruits. This accounts for their name cotton stainer bugs.

3.1.1. Description and Life History

With the exception of the peaks of dry seasons *Dysdercus* can be found year round in East Africa (Vosseler 1905a). Early rains stimulate new cycles of activity, as adults emerge from their shelters in bark crevices.

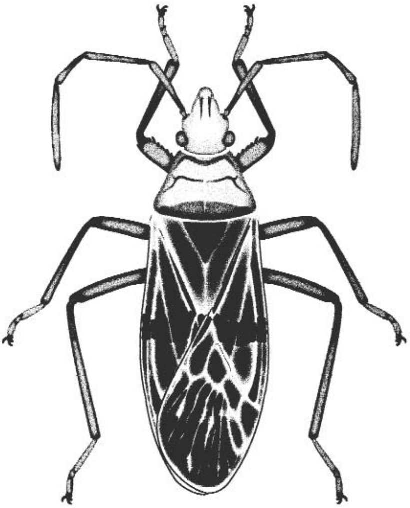


Figure 7-11. Dorsal view of *Dysdercus superstitiosus* (Pyrrhocoridae). (P. Schroud).

Eggs are laid in batches of 7-10, each generally containing between 56 and 106 eggs, for a total that may exceed 1,000 (Hill 1983; Schaefer and Panizzi 2000). They are ovoid and white, turning to yellow or orange, and measure 1.4 x 0.9 mm. Oviposition takes place at night in moist soil or plant debris.

Nymphs hatch after 4-12 days. While the first instar stays underground and does not feed, the second and third instars congregate in large groups on seed on or near the ground to feed or molt. Subsequent instars move freely in search of food. Depending on species and environmental factors, the five instars last 2-7, 4-9, 4-10, 5-11 and 7-18 days. Nymphs change from yellow to orange to red as they grow (Schmutterer 1969). Mature nymphs are 1-2 cm long, and bright red with black wing pads.

Adults (Figure 7-11) are even more colorful, typically featuring reds, yellows, blacks and whites (Freeman 1947). Depending on the species, they measure from 8-30 mm long, with females being slightly larger than males (Schuh and Slater 1995). The head is almost triangular. The compound eyes are prominent and conspicuously dark. The bugs readily drop and run when disturbed and fly strongly over long distances. During the day, both nymphs and adults rest in shadowy retreats and begin feeding in late afternoon. Mating occurs 2-3 days after emerging. Following a 5-14 day pre-oviposition period, females and males live an average of 60 and 66 days, respectively. Perhaps as a result of exhaustion from the massive egg production, females are generally shorter-lived than males (Schuh and Slater 1995). In a Tanzanian laboratory, total developmental period from egg to adult for *D. intermedius*, a strongly arboreal species, was about four weeks (Kasule 1985). Besides being pests, *Dysdercus* spp. are also popular as experimental animals.

3.1.2. Management

Controlling stainer bugs to prevent damage to cotton has been uniformly difficult, mostly because of the juxtaposition of abundant wild host reservoirs with crops. Trees have been suggested as trap crops, on which aggregations of the pest can be

destroyed by blowtorch or handpicking. Vosseler (1905a) also detailed a baiting procedure involving mature baobab fruits split in half and placed 10-20 m apart between cotton plants. As the bugs have a strong affinity for these fruits, they can be collected there periodically. Vosseler (1905a) suggested that baobab fruit should be stored for this purpose and exported to areas lacking this tree but experiencing problems with *Dysdercus*.

A number of mostly hemipterous predators reportedly attack cotton stainers, most intriguingly so several species of *Phonoctonus* (Vosseler 1905a; Villiers 1952; Stride 1956; Couilloud 1989). These assassin bugs (Reduviidae) lay their eggs among pyrrhocorid bugs, and exclusively prey on the bugs. As Müllerian mimics they often closely resemble their prey in appearance, shape and color (Stride 1956; Bohlen 1973; O'Toole and Preston-Mafham 1985). The predator is, however, slightly larger and has a smaller head with long neck, bulging eyes and a stronger, shorter, curved proboscis (Vosseler 1905a). The related bugs, *Platymeris rufipes* and *Atelocera* spp., are less specialized predators. In Sudan, a tachinid fly parasite has also contributed to natural control of stainer bugs (Schmutterer 1969).

3.1.3. Other Tree Pyrrhocorids

Antilochus sp. and *Odontopus exsanguis* Gerst. are listed in conjunction with *Ceiba pentandra* (Le Pelley 1959).

3.2. Scutelleridae: Shield-backed Bugs

Unlike their close relatives, the flattened stink bugs (Pentatomidae) mentioned in chapter 4, shield-backed bugs appear domed, are often brilliantly colored and their mesoscutellum is so much enlarged that it covers most of the abdomen as one shield. All are plant feeders on many hosts, usually flowering shrubs and trees.

3.2.1. Calidea spp.*: Rainbow or Blue Bugs*

This genus is the best known of the shield bugs and the most striking in appearance. There are five very similar species in different parts of sub-Saharan Africa, Madagascar and Arabia (Freeman 1939). Of these, four, *C. bohemani* (Stal.), *C. humeralis* (Walker), *C. dregii* Germar and C. *duodecimpunctata* (F.), are restricted to the eastern half of the Afrotropics. These bugs are highly polyphagous and the adults attack seeds of many cultivated and wild plants, especially woody plants such as *Crotalaria, Croton, Combretum* and *Euphorbia* (Le Pelley 1959; Hill 1983). Some are important pests of cotton and have forced growers to abandon this crop in certain areas of Tanzania (Hill 1983). Like stainer bugs, they do not only destroy seed, but also vector pathogenic fungi (Freeman 1939).

Eggs are spherical, about 1 mm across, at first white, then red (Hill 1983). They are laid in batches of up to 40 in a spiral around various parts of mostly wild hosts. Nymphs are oval and flattened, but otherwise resemble adults. The adult bugs

(Figure 7-12) are brightly colored, about 8-17 mm long and 4-8 mm across. They are red or orange underneath and iridescent blue or green above, with conspicuous spots and stripes. They are convex above and below, especially the pronotum and head. The complete life cycle takes about 23-56 days (Hill 1983).

Figure 7-12. Rainbow bugs, *Calidea* sp. (Scutelleridae), feeding on fruits of *Croton.* Arusha National Park.

3.2.2. Miscellaneous Other Shield Bugs

Atelocera stictica Westw. occurs on eucalypts and *Halyomorpha* sp. on *Cassia splendida* in Tanzania (Le Pelley 1969). One group of shield-backed bugs, called Picasso bugs (*Sphaerocoris* spp.), although not tree-related, are notable because they combine an artful design with edibility, in other words, they provide both a visual and a culinary feast.

4. FRUIT- AND SEED-FEEDING LEPIDOPTERA

Very little is known about fruit- and seed-destroying caterpillars in East Africa. Certain species are significant pests in the temperate zones.

An unidentified small caterpillar was found to be very abundant as a destroyer of fruit and seed of *Juniperus procera* in the Usambara Mts. (Morstatt 1912c). The caterpillars were described as about 6 mm long and yellow-green with a brown head. They develop in about seven weeks, and are detectable from the outside by frass extrusions. Pupation occurs in a brown cocoon on the fruit or in its neighborhood. The silvery grey adults with black dots are 7-8 mm long, including the wing tips. Hind wings are a uniform silver-grey. Eggs are laid on the young fruit. Several parasitic wasps hatched from the infested fruit.

Four species of pyralids associated with tree fruit and seed were listed by Gardner 1957a. Of these, the caterpillars of *Mussidia fiorii* T. and de J. were frequently found in the sausage fruits of *Kigelia aethiopica,* those of *Audeoudia haltica* Meyr. consumed the seed of *Spirostachys africana,* and larvae of *Plodia interpunctella* Hb. were recovered from stored seed of *Pinus palustris*. *Udea ablactalis* Walker was observed feeding on flowers of the sausage tree. Another pyralid, *Hypsipyla robusta* (Moore), is most consequential as a shoot borer of mahoganies, but in parts of its wide range, usually rain forest zones, may also attack flowers and fruits. It is dealt with in chapter 5.

Cryptophlebia (Argyroploce) leucotreta (Meyrick) is a serious pest of citrus and other cultivated or wild fruits such as *Ficus* in many parts of sub-Saharan Africa, but it is also known to destroy seed of *Maesopsis eminii* in Uganda (Gardner 1957a). Fruits attacked develop small spots surrounded by a premature ripened zone. A soft rot follows and the fruit sheds prematurely (Hill 1983).

CHAPTER 8

ROOT AND ROOT COLLAR FEEDERS

1. INTRODUCTION

Both chewing and sap feeding insects infest tree roots. They attack either from the outside or by boring inside the roots. Parts of, or entire roots of plants may be consumed, usually a function of size. In some cases, only the root collar is attacked. The results of root damage include growth loss, poor health and, in seedlings, often mortality. Secondary damage may result, when the lesions become ports of entry for pathogens.

Throughout the world, the complex of soil pests tends to be fairly uniform. Aside from non-insects such as rodents, nematodes and millipedes, the most important representatives include Coleoptera (weevils, white grubs and wireworms), Hemiptera (cicadas), Isoptera (termites), Lepidoptera (cutworms) and Orthoptera (crickets and mole crickets).

In most cases, only the immature stages of root insects cause damage, while the adults rely on other food or do not feed at all. Chafers, for instance, the adult stage of white grubs, are tree defoliators or flower feeders. While cicada nymphs are root sap feeders, the adults are sap feeders on above ground parts. In the case of termites and crickets, both stages cause similar damage.

White grub and cutworm infestations tend to occur with regularity, while those of other beetles, orthopterans and cicadas are more sporadic. Termite damage is highly predictable on certain sites in semiarid areas, usually on deep, well-drained soils high in clay but low in humic content. Although certain termites are important root and root collar feeders, they are discussed separately in chapter 6.

As a result of their hidden existence, very little is known about the role of root and root collar insects in Tanzanian forestry. Most representatives are polyphagous and thus tend to be known best in agricultural contexts. However, as most root and root collar feeders other than cicada nymphs are pests of young plants including tree seedlings and saplings in tree nurseries and young plantations, this group of insects is likely to become more important and needs to be better researched in conjunction

with this country's ambitious afforestation and restoration projects. Also, in sequential agroforestry systems, it is mostly soil-borne and diapausing insects that cause and perpetuate damage (Rao et al. 2000).

In nurseries, controls have traditionally relied on pesticides as well as biological or cultural controls.

2. ROOT-FEEDING COLEOPTERA

2.1. Curculionidae: Seedling Girdler Weevils

Two species of *Alcidodes* spp. commonly occur in East Africa. The striped sweet potato weevil, *A. dentipes* (Oliver), is best known as an agricultural pest of sweet potato and other crops, but it also attacks woody legumes throughout tropical Africa. The adult weevils are about 14 mm long with pronounced spines on the inner edge of all tibiae and front femora and conspicuous longitudinal stripes along the wing covers (Hill 1983). The adults girdle stems just above ground level causing the plant to wilt and die, while larvae bore inside the stem of host plants leading to galls.

The adults of *A. simplex* Fhs. are active in March, when they girdle young *Dombeya* and then lay one or more eggs below, covered by a frill of fibers (Gardner 1957a). While the larvae feed and pupate there, the stem above the girdle swells and eventually dies.

2.2. Elateridae: Wireworms or Leatherjackets; Skip-jacks or Click Beetles

This is a family of about 9,000 species of small to large (4-80 mm long) beetles. Adults feed on foliage, flower petals or pollen, while the larvae either scavenge, feed on roots underground, or prey on other invertebrates. Although there is little specific information concerning the significance of wireworms in Tanzania, most species are considered root-feeding pests (Watkins and Walker 1957).

The main damage to plants is caused by the larvae, slender, shiny brown, cylindrical insects with short legs. Because of their sclerotized, tough skin they are called wireworms or leatherjackets.

Adult click beetles are spindle-shaped, flattened, mostly dull-colored insects. Typically, the posterior angles of the large pronotum extend into sharp points. The antennae are thread-like, saw-like or carry a series of large, narrow paddles or lamellae. The beetles are best known and named for their ability to right themselves when stranded on their backs, accompanied by a clicking sound. When disturbed, they play dead and then try to escape by "skip-jacking". They accomplish this by forcing a thoracic spur through a narrow notch between the first and second thoracic segment. Adults are mostly nocturnal and are attracted to light. Eggs are laid in soil and plant matter, and larvae typically live for years.

The giant skip-jack or giant acacia click beetle, *Tetralobus flabellicornis* L., occurs from Senegal to South Africa. It is typically associated with large acacias. This insect was initially suspected to be a coconut pest along the coast of German East Africa (Vosseler 1905b; 1907c), but as it was not abundant and no relevant evidence emerged, it was eventually declared "probably harmless" in this crop (Morstatt 1911). This insect is considered edible in parts of Africa and is also sought by collectors. The beetle (Figure 8-1) is 60-80 mm long, smooth, dark brown and covered with a brownish-grey down that rubs off easily, leaving bare spots. The antennae carry large lamellae in males and are saw-like in females. The hairy larvae are variously said to live in termite nests (Moffett 1958) or to be pests of cotton. As big as this beetle is, amazingly few solid facts seem to be available concerning its biology.

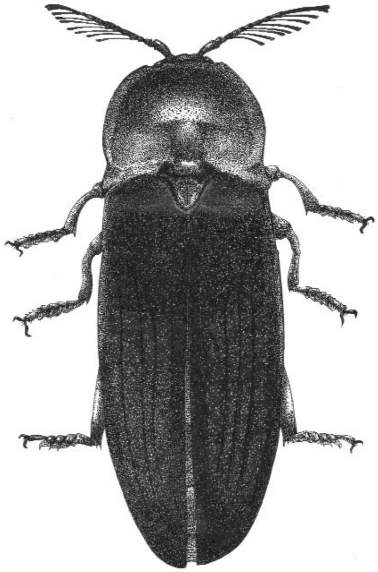


Figure 8-1. Male of the giant acacia click beetle, *Tetralobus flabellicornis,* with the typical shape of beetles in the family Elateridae. (B. Anderson).

2.3. Scarabaeidae: White or Chafer Grubs; Chafer Beetles

Most white grubs belong to the subfamily Melolonthinae which contains about 8,000 species worldwide. Included are a number of economically important pests in numerous crops, including trees. These larvae may be the single most important group of root feeders of trees worldwide while the adult beetles cause damage as defoliators or flower feeders. Host symptoms resulting from root-feeding, i.e., poor growth or wilting, are frequently misdiagnosed, as they mimic other soil problems, such as drought, nematodes or nutrient imbalances.

Both stages prefer young tissues. In Tanzania, the larvae are generally of greater concern than the beetles. Most problems arise in tree nurseries. The first record goes back to German days when hundreds of white grubs were reported in root balls of eucalypts (Vosseler 1904-06). Seedlings are most susceptible during the rains, and humic soils are more likely to invite infestations.

2.3.1. Description and Life History

The larvae are plump, cylindrical grubs, usually curled into a C-shape and with a slightly bulbous, dark-tipped abdomen. The chafers are small to big, robust, bulbous, black to brown or yellowish beetles (Figure 8-2). The lamellate antennae are characteristic for the entire family. The nocturnal beetles are attracted to lights.

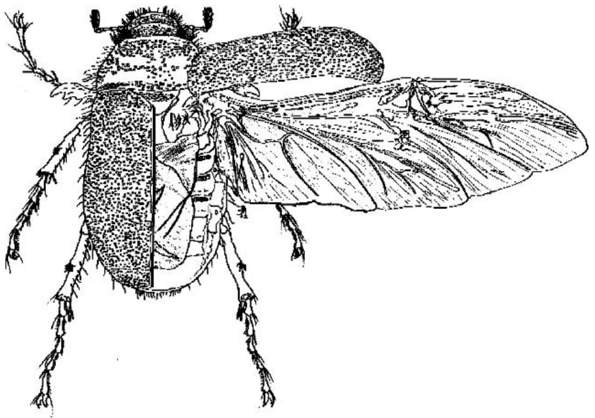


Figure 8-2. A Tanzanian chafer beetle (Scarabaeidae). Adults are defoliators, while the larvae (white grubs) are notorious nursery pests feeding on seedling roots. (P. Schroud).

As a result of their subterranean habit, virtually nothing is known about most white grubs of Tanzania with the exception of the sugarcane white grub *Cochliotis melolonthoides* (Gerst.). As a result, this species can serve to represent the general life history of other Melolonthinae.

Beetles in the genus *Cochliotis* are common in Africa. *C. melolonthoides* was previously only recorded as a rarity on the wooded slopes of Kilimanjaro and other mountains. However, with the expansion of sugarcane monoculturing in parts of Tanzania, this beetle spread considerably. It is now a serious root pest of sugarcane in this country, but the roots of many other plants and trees are also subject to attack (Jepson 1956). During heavy infestations, 20,000-100,000 grubs were documented per acre.

The beetles hide in soil during the day and emerge as strong fliers in the evening, following rain. They are fat, brown insects, 20-28 mm long, with a faint pale speckling of white scales over the body (Booth et al. 1990). The sexes are almost identical. Eggs are sub-spherical, whitish and are deposited in the soil deep enough to ensure moisture for development. They hatch after 10-25 days and go through three larval instars. The grubs are very difficult to distinguish from co-existing, less significant white grubs, as clarified by Jepson (1956). The first instar takes about a month to develop, the second a little longer and the third (Plate 56) more than six months. After feeding for 3-4 months, the third instar becomes inactive at a depth of about 0.5-1 m. Eventually pupation takes place in an earthen cell, and adults hatch after about a month. In Tanzania, eggs and early instars are abundant from December onward, while third instar larvae are most abundant from June-August. Adults emerge in two waves, a major one in October-November, and a lesser one at the onset of the long rains in March. The life cycle takes about one year to complete. Infestations typically build up slowly and eventually subside on account of natural controls, especially soil-borne entomopathogenic fungi such as *Cordyceps barnsii*, *Beauveria bassiana* and *Metarhizium anisopliae*. An integrated control program, including cultural, chemical and biological measures was suggested by Jepson (1956) and Hill (1983). In 1948, the giant cane toad, *Bufo marinus*, was imported to Tanganyika for biological control of this pest. As this toad can cause more problems

than it solves, it fortunately failed to become established, due to predation by monitor lizards (Hill 1983).

2.3.2. Other White Grubs

Several tree feeders are listed among other East African white grubs (Le Pelley 1959). *Schizonycha* is a common genus of 7.5-23 mm long beetles with over 300, mostly African species (Booth et al. 1990). These grubs commonly damage *Acacia mollissima*, as do those of *Autoserica lucidula* Per.

Certain leaf chafers in the subfamily Rutelinae have habits similar to the Melolonthinae in that the adults are defoliators, and most larvae are root-feeding white grubs. These are smaller, often brilliantly metallic beetles visiting flowers during the day. The hind tarsal claws are unequal and movable, while in the Melolonthinae they are equal and immobile. The larvae from the two groups are very difficult to separate (Jepson 1956). Many species of *Adoretus*, *Popillia* and *Anomala* were listed for East Africa, mostly on non-woody hosts, except for two species of *Popillia* from *Acacia mollissima* and *Cassia*, respectively (Morstatt 1913b; Le Pelley 1959; Booth et al. 1990). This genus includes serious pests in other parts of the world, but seems insignificant in East Africa.

3. ROOT-FEEDING HEMIPTERA

Only one group, the Cicadidae, commonly referred to as cidadas or Christmasbees, are of interest in this context. There are almost 2,000 named species worldwide, mostly in the subtropics and tropics. The shrill, buzzing sound, with which male cicadas attract their mates, belong to the African summer as much as thunderheads, rainbows and the cooing of doves. Most cicadas are associated with trees. Nymphs and adults extract sap from tree roots and branches, respectively. Furthermore, females cut 2-5 cm long egg slits into the bark of tree branches or trunks. This may lead to dieback or breakage, although trees often succeed in sealing this injury (Figure 8-3A). Overall though, African cicadas appear to be minor pests. Le Pelley (1959) listed only one cicada, *Ugada limbata* F., in conjunction with *Eucalyptus globulus* in Kenya. In Zimbabwe, this and other species (*Afzeliada* and *Ioba*) are collected for human food (Rice 2000).

Nymphs have modified fore legs suitable for digging in soil. As a result of their subterranean lifestyle, only mature nymphs or their shed skins are seen clinging to the lower part of tree trunks after they emerge from the ground (Figure 8-3B).

Adult cicadas (Figure 8-3C) are small to mostly medium and occasionally very large insects. These strong and fast fliers have stiff, membranous, transparent and often colored wings, with spans usually from 40-90 mm. At rest, the wings are held roof-like over the body, and the front wings extend well beyond the tip of the abdomen. Cicadas have inconspicuous, hair-like antennae, big compound eyes, three

simple eyes and piercing-sucking mouthparts typical for the order. The sexes are similar, except that males have a pair of circular sound organs (tymbals) located on either side of the first abdominal segment while female cicadas sport a short, spear-like ovipositor near the tip of the abdomen.

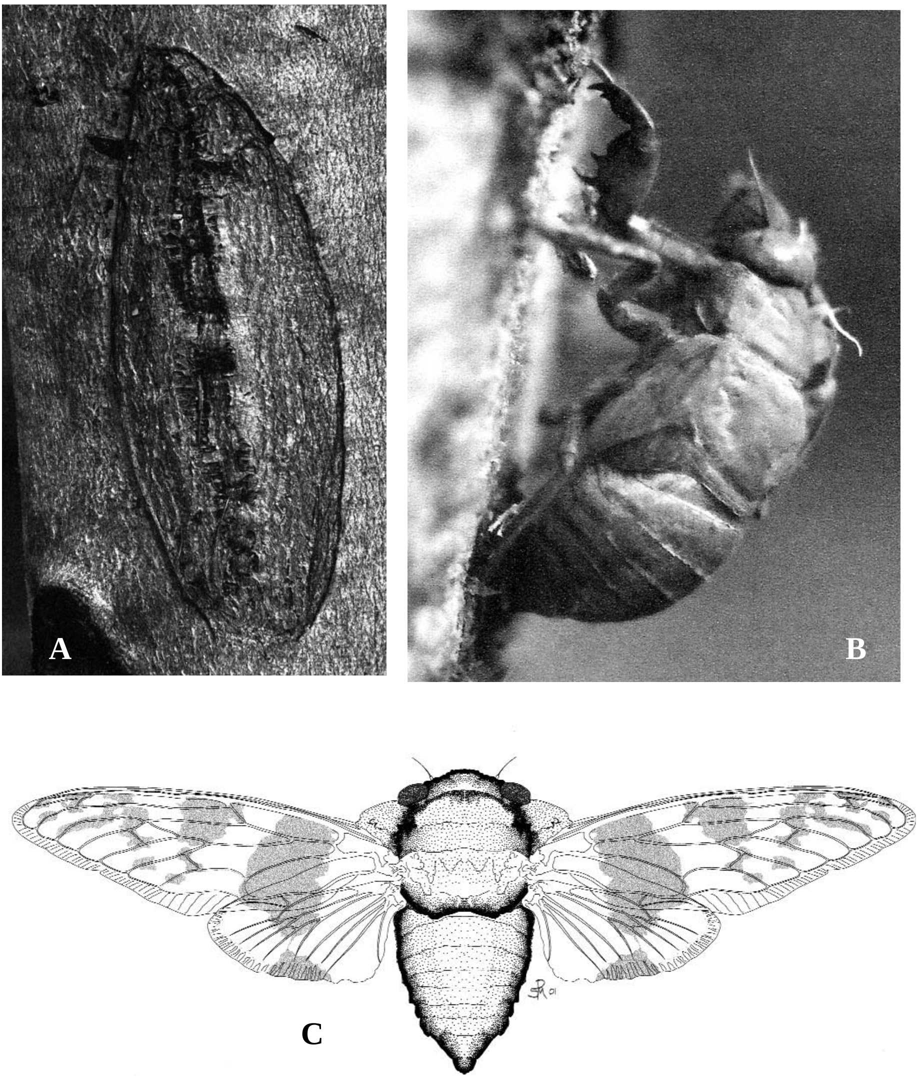


Figure 8-3. Cicada (Cicadidae). (A) Old cicada oviposition scar on bark of *Eucalyptus camaldulensis.* (B) Exuvia of cicada nymph attached to lower tree trunk showing the fossorial front legs of this root-feeding stage. January, Manyara. C. Adult of *Ioba leopardina.* (P. Schroud).

Given the audibility and visibility of cicadas, it is surprising how poorly known the biology of afrotropical species still is (Picker et al. 2002). A very recent investigation in South Africa appears to be the first detailed study of an African cicada (Malherbe et al. 2004). In South Africa, cicadas seem to be associated with certain hosts such as *Acacia*, *Albizia*, *Brachystegia*, *Cassia*, *Delonix*, *Dichrostachys* and *Ficus* among others, on whose sap they feed and/or on which they lay eggs. Three to 20 eggs each are inserted into cuts in the bark, for a total of perhaps 400-600. These take about six weeks to hatch (Skaife 1979). The newly hatched nymphs drop to the ground to live as sapsuckers on the roots of, at first grass, then woody plants. In other parts of the world nymphal development is known to take as many as 17 years while tropical cicadas require perhaps 2-6 years. This long development may be a function of the diluted, nutritionally poor xylem sap consumed. There are five instars. When approaching the end of the nymphal stage, some South African species build a chimney or cone of earthen particles, glued together by saliva and projecting 10 cm or so above ground in which the nymph may live for weeks before finally emerging (Skaife 1979). Synchronized mass emergences of cicadas have been reported from different parts of the world. Unlike the long-lived nymphs, adult cicadas die after a few weeks.

4. ROOT COLLAR-FEEDING LEPIDOPTERA

Most important in this context are the cutworms or caterpillars of certain owlet moths (Noctuidae (=Agrotidae)). With about 21,000 species, the largest family of Lepidoptera worldwide, the noctuids are well represented in East Africa. Many Tanzanian species have a narrow distribution, while others have a strong affinity with South Africa (Dall'Asta 2004). This family includes some of the worst agricultural pests and notorious pests of tree nurseries throughout the world. Damage results from defoliation of seedlings, but is most insidious when the caterpillars bite off the entire plant at the root collar, including young trees in many species, often destroying several in one night. Cutworm damage starts soon after planting and lasts for about two months, i.e., the period during which the seedling stems are succulent.

4.1. Description and Life History

Owl moths are mostly dull buff, grey to brown with lighter-colored hind wings and wingspreads of around 30 mm. Their antennae are whip-like. A few species defy this general model though. Walker's owl *Erebus macrops*, Tanzania's largest noctuid, a defoliator of *Entada*, has a wingspread of 120 mm and is marked with two showy eyespots. The diurnal peach moth, *Egybolis vaillantina*, is only half this size, but is a very showy metallic blue-green with bright orange bands and dots.

Standard cutworm larvae are grey, brown, green or black caterpillars, about 30 mm long, near naked and plump. When disturbed they curl up. Some are semi-loopers with only three pairs of abdominal legs. Most of the pupae are simple and naked.

Both the caterpillars and moths are nocturnal, the former spending the day underground. During the winter, cutworms rest as mature caterpillars and pupate as warmer weather arrives. The moths hatch 2-3 weeks later. Females lay as many as 1,500 eggs on the food plant and larvae hatch two days to one week later. After feeding for a few days, they hide in the soil, only to emerge at night. Pupation occurs after 2-4 weeks of larval existence about 25 mm below the surface, and adults hatch another 2-4 weeks later, except in the estivating generation. There are up to eight generations per year (Hill 1983).

4.2. Major Forest Cutworms

Among a number of cutworms observed in East Africa (Gardner 1957a; Le Pelley 1959; Austarå and Jones 1971; Hill 1983), the following were mentioned for Tanzania.

Agrotis (=Euxoa) segetum Denis & Schiff (Figure 8-4) is the most common cutworm in forest nurseries in East Africa (Gardner 1957a). At Iringa, Kibosho, Lushoto and Moshi it defoliated and cut numerous seedlings of herbaceous crops as well as *Casuarina*, *Hagenia*, and several species of eucalypts and pines (Austarå and Jones 1971). The larva is smoky black (Hill 1983).

Ariathisa excisa H.-S. did similar damage to pine and Douglas fir (*Pseudotsuga menziesii*) in a nursery at Lushoto (Austarå and Jones 1971).

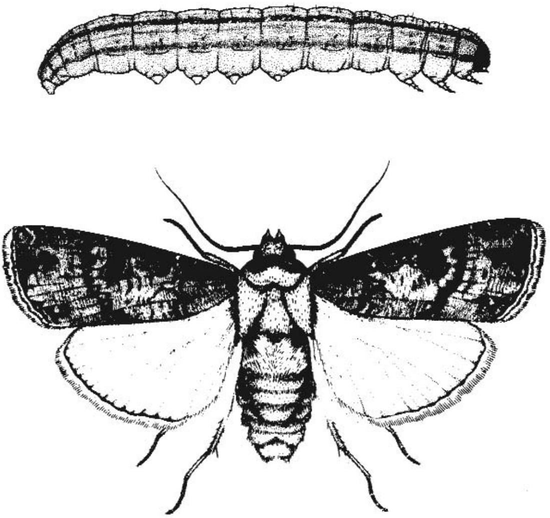


Figure 8-4. Agrotis segetum (Noctuidae) caterpillar (above) and moth of this most notorious of cutworms in Tanzania. (From Hill 1983).

Rather than as cutworms, a *Celama* sp. was mentioned as defoliating (?) *Albizia* on the mainland, while *Roeselia infuscata* Hmps attacked *Terminalia catappa* in Zanzibar (LePelley 1959). In Zambia, two polyphagous noctuids, *Trichoplusia arichalcae* (F.) and the cosmopolitan, Old World bollworm *Heliothis (=Helicoverpa) armigera* (Hübner), defoliated a young *Pinus kesiya* plantation in an outbreak that abruptly ceased after three months (Selander and Bubala 1983). Although it does not attack trees, *Elaeodes prasinodes* Prout. is of interest as the caterpillars occasionally completely defoliate bracken fern (*Pteridium aquilinum*), an insidious weed that complicates forest regeneration (Gardner 1957a).

4.3. Management

A number of natural enemies attack cutworms. During one study of *H. armigera* in Tanzania, 12 species of parasites were obtained, three being of greatest relative importance (Robertson 1973). In one case, the rate of parasitism rose from 0.7% in February to 46.9% in June. Nevertheless, standard control of cutworms in forest nurseries everywhere tends to rely on the use of pesticides (Govender 1995).

5. ROOT-FEEDING ORTHOPTERA

Certain field crickets (Gryllidae) and most mole crickets (Gryllotalpidae) are nursery pests in many parts of the world, killing seedlings of herbaceous and woody plants by consuming the roots or the entire plant. These insects are usually brown to black, nocturnal insects with 3-jointed tarsi.

5.1.Gryllidae: Crickets

5.1.1. Brachytrupes membranaceus (Drury): *Giant, Sand or Tobacco Cricket*
This insect is widely distributed in tropical Africa (Schmutterer 1969; Hill 1983). At night, both nymphs and adults cut seedlings at ground level, often leaving stumps. They drag the leaves or entire seedlings fresh or wilted into underground burrows, either for consumption or storage. During the dry season, dead tree leaves are collected instead (Taylor 1981). In different parts of Africa, host plants include many agricultural and wild crops, but also species of pines, eucalypts, *Casuarina*, *Thuja*, *Brachystegia* and *Julbernardia*, among others (Brunck 1965; Taylor 1981). Damage is most evident in nurseries (Esbjerg 1976), but can be substantial in the field as well. In one instance, 50% of newly planted seedlings of eucalypts were destroyed which was attributed to the elimination of alternate sources of food by clean cultivation (Taylor 1981).

These crickets (Figure 8-5) are up to 75 mm long, fat, shiny, and dark-brown with yellow front and mid legs. The head is square and heavy and carries long thin antennae. The powerful jumping hind legs bear numerous spurs. The venation of the forewings in the male is irregular and coiled, while that of females is characterized by more normal parallel lines.

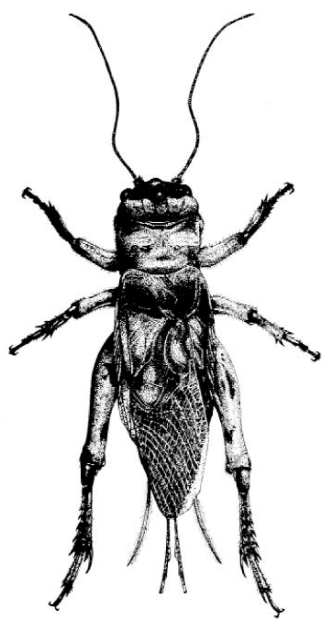


Figure 8-5. The giant cricket *Brachytrupes membranaceus,* a destroyer of seedlings, but valued as a delicacy. (B. Anderson).

As a largely nocturnal insect living underground, this insect is rarely seen. During the rains its song can, however, be heard over a distance of one and a half kilometer (Scholtz and Holm 1985). Adult females live for about 3-4 months, during which time they lay over 300 elongate-oval, 3-6 mm long, white to brown eggs. Nymphs hatch after about one month. They leave the burrow of the mother and establish their own, gradually enlarging it as they grow. In sandy soil, this tunnel may eventually reach a depth of 60-80 cm and include thumb-sized main and emergency exits, a food and living chamber as well as connecting runs. There are four instars during a total nymphal period of about eight months. Full-grown nymphs are 4-5 cm long fat, brown insects. The adult stage is reached at the start of the rainy season and eggs are laid in batches in the burrow 3-4 months later. In Zimbabwe, there is one generation a year (Taylor 1981).

When control is deemed necessary, bran bait mixed with pesticide or chopped, poisoned green plants are broadcast between crops in the evening (Taylor 1981; Hill 1983). Nymphs and adults of this cricket are edible, although rarely available in quantity (Harris 1940).

5.1.2. Gryllus bimaculatus Deg.: *Two-spotted or Common Garden Cricket*
This widely distributed cricket ranges in a long arc from Indonesia through southern Asia, East and South Africa, and parts of Europe as far as Gran Canaria. It feeds on the roots of many plants or cuts the collars of seedlings, especially in nurseries. It was labeled a pest of vegetables and ceara rubber trees in German East Africa (Morstatt 1913b). This cricket is also sought as human food, raised for pet food, and is commonly employed as an experimental animal in laboratories.

The garden cricket is usually encountered during the rains (Schmutterer 1969; Hill 1983). The yellow eggs are oblong and banana-shaped. They are laid in many batches of about 10 each, for a total of several thousand. Nymphs hatch after about 12 days. High moisture content of the soil is crucial both for laying and for development. Eggs developing in the absence of water produce dwarfed hatchlings (Scholtz and Holm 1985). Mature nymphs are brown to blackish. The adults are up to 25 mm long, shining dark brown (female) to black (male), with yellowish patches at the base of each front wing. They are mostly nocturnal and during the dry season hide in soil cracks.

5.2. Gryllotalpidae: Mole Crickets

5.2.1. Classification
Mole crickets occur in five genera and about 60 species throughout the tropics and warmer temperate regions of the world. The largest genus, *Gryllotalpa*, is restricted to the Old World. Until recently, most of the common African, Asian and Australian species of *Gryllotalpa* were lumped together under the name of *Gryllotalpa africana* Palisot de Beauvois. A revision of the afrotropical mole crickets showed, however,

that the true *G. africana* does not occur outside Africa, and even in Africa other species may be responsible for some of the damage that had previously been attributed to *G. africana* (Townsend 1983). According to this revision, 12 species of *Gryllotalpa* are now recognized for Africa. Based on differences in stridulatory teeth and wing venation, they are separated into two distinct groups called "*africana*" and "*parva*". Seven of the 12 species, four from the "*africana*" group (*G. africana*, *G. bulla* Townsend, *G. debilis* Gerst., *G. robusta* Townsend) and three from the "parva" group (*G. brevilyra* Townsend, *G. microptera* Chopard, *G. parva* Townsend) occur in Tanzania. The new *G. africana* is still properly named, as it occurs throughout the African continent.

5.2.2. Damage

Depending on species, *Gryllotalpa* either are mainly predaceous, mainly vegetarian or omnivorous. Some are sporadically serious root and root collar feeders that kill turf and ornamentals as well as agricultural crops and tree seedlings in nurseries or propagating beds (Vosseler 1907; Townsend 1983). Small seedlings may disappear completely overnight, while older ones wilt. Even carnivorous species may do damage with their extensive burrowing. Moist soils at lower elevations are the most common trouble spots, but different species of Gryllotalpa have different soil preferences. Heaps of soil mark the entrance to the permanent, up to 1 m deep complex of underground burrows, where both nymphs and adults live.

5.2.3. Description and Life History

Members of the family are easily recognized insects of rather uniform appearance. Most prominent are the shovel-like forelegs that allow digging in soil (Figure 8-6). The new *G. africana* averages a little over 28 mm long, while the other species are up to 7.5 mm shorter. Like other *Gryllotalpa* spp., it has a velvety brown appearance, a large pronotum, relatively short antennae and fairly large cerci (Scholtz and Holm 1985). The forewings are short, and the hind wings are folded into a narrow fan. The tips extend beyond the abdomen in two spikes covering the body incompletely.

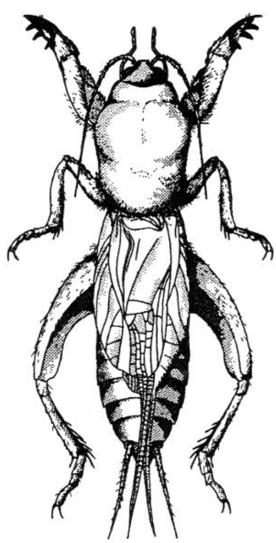


Figure 8-6. An African mole cricket, *Gryllotalpa* sp. (Gryllotalpidae). (From Scholtz and Holm 1985; reproduced by permission of University of Pretoria, SA).

Adults rarely fly, but when they do they are attracted to light. To call in a mate, males stridulate with the forewings, making a deep buzzing sound from a special singing burrow near the mouth of their tunnel system Scholtz and Holm 1985).

Eggs of *Gryllotalpa* are oval, brown and 1.5 mm long. During the rainy season they are laid in chambers at the end of burrows 10-15 cm below the surface. The female constructs three or more of these chambers and lays a total of about 100 eggs distributed among them. Eggs hatch after 2-3 weeks. First instar nymphs remain in the egg chamber and are fed by the mother. Later instars live in burrows and, like the adults, search for food on the soil surface at night. There are 9-11 instars and the total nymphal period lasts about 10 months. Mating takes place about 10 days after the last molt and oviposition begins 1-2 weeks later. Adults live for at least two months and possibly for lengthy periods. The total life cycle takes about a year and two overlapping generations may exist in the field.

5.3.4. Management

As for other crickets, control measures rely on pesticide-laced bait (Hill 1983). Mole crickets are sought as human food or feed for some domestic animals.

CHAPTER 9

FOREST-BASED INSECT INDUSTRIES

1. INTRODUCTION

Continued rapid human population growth is accelerating rates of resource degradation and depletion throughout the tropics, jeopardizing the livelihood of people dependent on these resources and putting extraordinary strains on ecosystems and biodiversity. The concept of sustainable development is becoming a keystone of modern development policy, encompassing legal, institutional, technical and economic mechanisms to foster economic development while simultaneously safeguarding in perpetuity the natural foundations of human existence, i.e., soil, water, air and the extraordinary wealth of life on Earth. While traditional development models are largely based on sectoral thinking, leading to conflicts between various sectors, contemporary planning attempts to develop economies in a more integrated fashion through land use planning, establishment of biosphere reserves, and various innovative rural development schemes.

While the complete preservation of intact ecosystems is possible in some circumstances, resource problems in the human sphere frequently call for more realistic approaches, such as community-based conservation efforts. Unfortunately, the majority of forests in Africa that harbor high plant and thus animal endemism, are also characterized by a large human footprint (Küper et al. 2004). As a result of threats to these biodiverse resources, a dynamic period of change in development policies evolved in the 1990s to generate some creative experiments and solutions for nature conservation in the frontline states. One such program fosters local ownership and participation in resource planning and management of community property, as well as sufficient economic incentives for stakeholders to develop protective attitudes towards maintenance of sustainable community forests. Properly planned, implemented and monitored, as exemplified by the success of certain game and forest management programs in some parts of Africa and Asia, this scheme promises to simultaneously address the needs of the local inhabitants and the environment.

While the value of considering insects as “mini-game” or “mini-livestock” may not be immediately obvious, the analogy is compelling. As a forest-based wildlife resource, certain insects can be managed like other animals and have economic

potential at least at the subsistence level, if not at higher commercial scales. Four insect-based industries are of interest in Tanzania, including (1) the use of insects for human or animal food (entomophagy) (2) beekeeping (apiculture) (3) silk production (sericulture) and (4) the trade in collectible insects. As components in integrated resource management plans, any of these insect industries can play a role in the development of cottage industries, help alleviate rural poverty and hopefully mitigate the opportunistic exploitation of vulnerable forest landscapes.

Entomophagy and apiculture were of great traditional importance to certain Tanzanian communities, but cultural alienation from time-honored rituals, and excessive, non-sustainable rates of extraction have led to declining dependence on them over the last century. During the colonial and modern age, entomophagy developed a negative image in large segments of the general public, although the practice has survived to this day in various parts of rural Tanzania. But even in areas where insect feasting is accepted, certain groups of insects appreciated as nutritious and delicious elsewhere in the world may be completely ignored, probably for no better reason than traditional oversight, cultural taboos or readily available protein alternatives. Concerning beekeeping, Tanzania could readily revive what may have been Africa's strongest apicultural tradition and a potentially substantial national industry that is presently functioning far below its potential.

Although sericulture and collectibles do not have strong traditional roots in Tanzania, they are now being promoted as potentially rewarding, small-scale economic ventures. Silk-production may be most feasible in conjunction with artisan enterprises or export to West Africa, where traditional demand was strong but local supplies have recently declined due to deforestation. Given Tanzania's extraordinary biodiversity and wealth of showy, often endemic species of insects, their exploitation as a renewable resource for a growing international market of specimen collectors has barely begun, but must also be regulated to assure sustainability.

Interesting attempts to integrate several of these insect enterprises both with forestry and with each other are already underway in different parts of Africa. For instance, the International Centre of Insect Physiology and Ecology (ICIPE) in Kenya recently began projects to link sustainable apiculture and wild or domesticated sericulture to forest conservation in 16 countries in East and southern Africa (Herren 1998: Miller et al. 2000). Initial field tests by ICIPE indicate sizable income and rural employment potential from these industries. For instance, it is estimated that 0.4 ha of mulberry plantation in Kenya can produce 500 kg of silk cocoons in five rearing cycles per year and yield 70-75 kg of raw silk, generating a net income of US $ 1,600. Mulberry trees can be integrated into agroforestry schemes as multipurpose trees for fodder, sericulture, fuel wood, fruit and even bee pasture, as had already been realized in German East Africa in the early 20th century (Vosseler 1907e, 1920). Since two bee seasons are possible over much of East Africa, it is estimated that one household can reasonably be expected to manage 12 hives, each yielding US $ 25-30 per Langstroth hive and US $ 7-8 per traditional log hive.

Another example, combining caterpillar production with a traditional scheme of shifting cultivation was documented for Zambia. In this case, incomes over $ 60 per household from insect trading were generated even in years of moderate insect abundance, comparable to or exceeding incomes from the sale of agricultural crops (Chidumayo and Mbata 2002). Greatest caterpillar crops were obtained in the early years of the fallow cycle, i.e., when *Julbernardia paniculata,* the favorite miombo food plant of the most popular caterpillars, abounds as pioneer vegetation. The mean numbers of caterpillars collected from this tree species were significantly larger than those on other host plants (Mbata et al. 2002). Leguminous trees generally rank highly as forage for edible caterpillars (Turk 1990). Other projects in Malawi and Zambia try to revive and integrate traditional forest-based beekeeping and edible caterpillar utilization into community-based conservation, in the hope to provide sufficient incentives for sustainable use and nature conservation by locals (Mbata et al. 2002; Munthali et al. 1992). Both of these long-entrenched industries had recently begun suffering from forest depletion and concomitant shortages of caterpillar food trees and bee pasture.

German era experiments at Amani, exploring the production of the Indian wax scale (*Ceroplastes cerifer* Anders.) on *Acokanthera abessinica,* are of historical interest as a complement to the four insect-based industries discussed above (Lindinger 1907). At that time, the thick crust of white wax produced by these insects, generally known as “insect wax”, together with the scale insects themselves (used as food for swine), were an export item from Madagascar for use in candles, polish and the sizing for paper. The Germans hoped that new economic opportunities could be developed for German East Africa as well. However, this experiment at Amani appears to have failed, either for economic reasons, or because it was realized that this insect has significant pest potential. This originally Asian scale insect occurs now in Malawi, Tanzania and Uganda, as well as on all other continents. It is considered a serious pest of ornamentals and greenhouse plants in North America, and it may be in the process of becoming one in Europe.

While the development of insect-based industries is an attractive prospect, its reach and scope must be assessed realistically. Frequently, funding of development projects assures enthusiastic participation of stakeholders for the duration of the project, with no guarantee of continued activities afterwards. For instance, beekeepers involved in an apiculture project in Zanzibar lost interest at project closure, citing lack of advice, fear of bees, deforestation and poor marketing as factors (Raina et al. 2000). Sericulture in Africa has also had its ups and downs through the years, probably from lack of continuity and a solid basis of planning, research, development, training, infrastructure, investment and/or marketing. Despite competition from synthetics, the demand for silk has recently experienced 2-3% growth per year and sericultural prospects are considered bright (Raina et al. 2000). However, as always, market fluctuations are inevitable, and ceilings for certain crops such as wild silk, edibles and collectibles are likely to remain fairly low, unless creative marketing can

stimulate increased demand. How well an industry is able to weather the vicissitudes of economics ultimately determines its long-term viability. As a result, economic diversification and integration with other enterprises remain good strategies.

Until recently, economically important insects were an apparently inexhaustible resource. However, as has been the case with other natural resources worldwide, pollution, habitat destruction, harmful collection methods and excessive harvesting by unscrupulous profiteers and expanding populations have resulted in degradation. Even species that are hard to over-exploit may become vulnerable with habitat loss and deterioration. As a result, the concept of insect conservation has recently taken hold. This is particularly crucial for intrinsically rare, often endemic or remnant-dependent species that may not survive without legal protection and effective enforcement.

The Conference on International Trade in Endangered Species (CITES), signed in 1973, now involves 152 parties, providing vulnerable species of flora and fauna, including insects, three categories of protection. Appendix I lists species in danger of extinction for which no commercial trade is allowed. Appendix II enumerates those species threatened unless trade in them is regulated, while Appendix III includes unilaterally declared species for which cooperation from other parties is being sought.

In Africa, insect conservation programs started in 1976, when 16 butterfly species were included in the protected animal list of South Africa's Cape Province (McGeoch 2000, 2002). This country later developed the Ruimsig Entomological Reserve for the protection of a red data butterfly. Other insect conservation projects in South Africa include research on the use of certain insects as bio-indicators of environmental change, categorizing the country's rich and interesting insect fauna, and evaluating priority conservation areas. Since area protection for insect conservation inevitably benefits the conservation of associated flora and entire landscapes, it automatically provides ecosystem and possibly economic benefits, such as sustainable extraction schemes for certain resources and/or ecotourism. More such insect conservation programs are needed in other parts of Africa as well.

2. EDIBLE INSECTS (ENTOMOPHAGY)

Historically, traditional societies in parts of the tropics and beyond have routinely consumed insects for food, and some continue to engage in entomophagy to this day. Worldwide, over 1,000 species of insects are known to provide food for humans (DeFoliart 1995), including about 250 species of insects in sub-Saharan Africa that are or have been considered food items (Huis 2003). Unfortunately, in many parts of the world, western prejudice against entomophagy has stigmatized the practice. Oddly, the same people who reject insects as revolting, may lust for crustaceans such as shrimp, crayfish, prawns and lobsters, close relatives of insects. They also relish honey, the product of regurgitation by bees, and consider certain snails (escargots), oysters and other mollusks as among life's great pleasures.

2.1. Nutritional Benefits

During the last 25 years, attempts have been made to de-stigmatize entomophagy and even to broaden its appeal. This is reflected in numerous publications, most notably "The Food Insects Newsletter" and in policy recommendations that incorporate forest-gathered insects as non-wood forest products in food security and forest conservation strategies (Vantomme et al. 2004).

Research by ethno-entomologists increasingly provides data that legitimize these efforts, as the merits of entomophagy go far beyond supplying hungry people with a calorie-rich source of sustenance (Taylor 1975; DeFoliart 1989, 1995; Huis 2003; Latham 2003). In areas with seasonal shortages of affordable animal protein, insects may constitute an important staple or delicacy rich in protein, fatty acids, vitamins and essential minerals (Chavanduka 1975; Oliveira et al. 1976; Glew et al. 1999). For instance, the mopane worm (*Gonimbrasia belina* Westw.) of southern Africa has three times the protein content of beef by weight, and in Zaire alone insects are estimated to furnish about 10 % of total human consumption of animal protein. Eating potential pests or feeding them to domestic animals also provides an environmentally benign and economical alternative to pesticides. Given the nutritional merits of certain insects, even the raising of insects as micro- or mini-livestock has been given serious consideration (Osmaston 1951; DeFoliart 1989, 1995). Various medicinal benefits have been attributed to some insects, though these are as yet unsubstantiated by research. This is also true of the common practice of geophagy in many parts of Africa, where pregnant women eat soil associated with termite structures, supposedly to provide essential minerals (Huis 1996).

2.2. Preparing Insects for Food

To maximize quantity, insects are typically collected in advanced instars, as pupae or as adults. Soft-bodied insects may be eaten or processed in their entirety, while others are washed and have intestinal contents, wings, legs, spines and/or hair removed first. Some are eaten as snacks, fresh and raw on the spot, while others may become ingredients in meals, or are prepared as trade articles. Preparation includes boiling, grilling, stewing, frying, steaming and roasting in their own or other fats, such as butter or palm oil. Certain insects may be boiled repeatedly to eliminate offensive odors or to detoxify them, and hairs may be burned off. Others are prepared for long-term storage by sun- or smoke-drying, or ground into meal. Salt, red peppers or other spices can be added to enhance taste and prolong storage. The Malawi cookbook (Shaxson et al. 1985) provides recipes for nine species of insects commonly eaten in that country, that also occur in Tanzania.

2.3. Food Insects in Africa

Insects most suitable for consumption usually share certain characteristics. Aside from being proven safe, nutritious and often having a pleasant or interesting taste,

they are generally of medium to large size, at least seasonally abundant in predictable places, and easy to collect. Social insects such as termites or gregarious caterpillars, flies, cicadas and grasshoppers are favorites, as they are concentrated in mating swarms or feeding groups and can be easily harvested in quantity. Insects concentrated in tree logs and those attracted to light are also relatively easy to locate and collect in numbers. Termites can even be coaxed from their underground colonies and trapped in large numbers on emergence, involving various contraptions such as glue sticks, nets, brooms, baskets or baited traps (Huis 2003).

Most African insects suitable for entomophagy are members of one of seven orders: Coleoptera, Diptera, Hemiptera, Hymenoptera, Isoptera, Lepidoptera, and Orthoptera. Not all of these insects are uniformly embraced by all people, and some individuals within social groups may be restrained from entomophagy by taboos (Silow 1976; Huis 1996). In parts of the world, certain species in other insect orders (Trichoptera, Odonata), as well as some other arthropods (scorpions and spiders) may also qualify as food (Menzel and D'Aluisio 1998). Most of the insects consumed in Africa happen to be predominantly associated with forests, trees or wood and thus can be considered "forest insects". The lake or nkhungu (= kungu) fly (*Chaoboris edulis* Edwards) is a notable exception (Harris 1940a). This aquatic phantom midge (Chaoboridae) serves as an important, highly proteinaceous, caviar-like food for people near Lakes Victoria and Nyasa. Drifting in masses like smokescreens over the lakes, these flies are typically caught with long-handled baskets on shore, on wet sheets or blankets rigged to upright poles in canoes, or are attracted to lights at night. They are boiled, pressed and molded into cakes, and dried in the sun for later consumption or sale.

Below, an overview of forest insects used for food in Tanzania is presented, arranged by orders in an approximate sequence from greater to lesser importance. Food insects that are exploited in neighboring countries, where entomophagy is more widespread than in Tanzania, are also discussed, as they constitute a potentially underutilized resource. It needs to be emphasized, however, that unknown insects, like mushrooms, should be approached with caution, as documented cases of human fatalities from the ingestion of poisonous insects attest (Picker et al. 2002). As a response to predation, many insects have evolved evasive and defensive mechanisms, the most effective being the incorporation of chemical deterrents that make them unpalatable or toxic. Those insects typically advertise their toxicity or lack of palatability with warning (aposematic) colors and/or by oozing repulsive foams and odors, while others pretend to be unpalatable by mimicking aposematic models. In addition to being colorful, aposematic insects, lacking the need to elude predators, are often torpid, or are wingless and gregarious. As with mushrooms, specific preparation techniques may be used to detoxify some poisonous species.

2.3.1. Orthoptera

About 29% of edible insect species in Africa are members of this order (Huis 2003). The nymphs and adults of grasshoppers, katydids and crickets are "manna" for food

gatherers all over Africa (Bodenheimer 1951). In the Sahelian region, farmers are said to be reluctant to treat their crops with pesticides, for fear of jeopardizing grasshoppers that can be marketed more profitably than millet (Huis 1996).

According to Harris (1940a), the red (*Patanga septemfasciatata* (Serv.)), desert (*Schistocerca gregaria* Forsk.) and migratory locusts (*Locusta migratoria* R. & F.) were probably the most widely eaten insects in Tanganyika. Feared as crop pests wherever they occur, locusts are eaten fresh, roasted or fried in butter. They are rich in protein (47-59%) and fats (10-22%) and surprise with a "mild flavor reminiscent of shrimp" (Chavanduka 1975). They can also be dried and ground into salted flour for long-term storage (Bodenheimer 1951). Volkens (1897b), one of the first adventurous Europeans to try locusts, judged them "not bad at all".

The cone-headed or edible katydid *Ruspolia (=Homocoryphus)* spp., (Tettigoniidae), an occasional crop pest, is to this day considered a great delicacy, especially in Uganda, but also in other eastern, central and southern African countries, including Tanzania. The Haya call the insect nsenene for "November", as immense swarms of this insect arrive with the onset of rains followed by a second hatch in April (Harris 1940a). Nsenene were such a precious resource, that their capture and consumption was traditionally accompanied by a complex set of rules and rituals (Mors 1958). For instance, people were allowed to trespass to collect the insects, and while women and children prepared nsenene, it was only men who ate them. The katydids were considered esteemed gifts and valued so highly, that a wife's failure to collect them was considered grounds for divorce. The arrival of the edible katydid is often indicated by congregations of large flocks of Abdim's and white storks that gorge on these locusts (Loveridge 1944; Anon 1995). The insects are either collected at lights or in the morning, with or without the help of smoke.

Zonocerus spp. (Pyrgomorphidae), a polyphagous crop pest in many parts of Africa including Tanzania, is considered edible in South Africa, Cameroon and Nigeria, but not so elsewhere. This is puzzling, given the fact that this insect is a gregarious, aposematic pyrgomorphid, most of which are known to be toxic. The difference may be attributable to repeated cooking (Huis 2003) or perhaps differences in host plant composition and thus the chemical makeup of this insect (Anon 1994). In any case, this poses an interesting question that begs clarification.

In former times, Orthopterans played an important nutritional role near Kilimanjaro, where to this day children pursue certain grasshoppers for food (Hemp 2001a). The local vernacular makes a fine distinction between palatable grasshoppers (Thericleidae, Lentulidae and Acrididae) called "ndatari" and "nzihe" among other names, and inedible ones (Pyrgomorphidae) called "itanga". In 1998, following El Niño rains, swarms of the katydid *Ruspolia differens* Serv. invaded the plantation belt on the southern slopes of Kilimanjaro and children ate them fresh (Hemp 2001a).

The giant or sand cricket *Brachytrupes membranaceus* (Gryllidae), as well as other crickets, are also eaten roasted in various parts of Africa (Harris 1940a). The former is considered a delicacy in Zimbabwe “for it turns an ordinary meal into dinner” (Chavanduka 1975). In Uganda and Zimbabwe, mole crickets, *Gryllotalpa* spp. (Gryllotalpidae), are also considered food (Bodenheimer 1951; Huis 1996). The giant, as well as mole crickets are common nursery and garden pests. Crickets are either caught in baited traps or located by sound and dug out.

2.3.2. Isoptera

Soldiers and reproductives of the larger species of higher termites (Termitidae) are a widely sought animal food throughout tropical Africa (DeFoliart 1989; Anon 1995). They complement protein with high fat content and thus are energy-rich (Malaisse 1997). They also abound in magnesium and copper (Oliveira et al. 1976). Pooled with Hemiptera, Diptera and Odonata, they account for about 22% of edible insect species in Africa (Huis 2003).

On no other continent are termites valued as much as they are in Africa, where at least 10 genera in four families are eaten (DeFoliart 1995). Their nutty taste makes them quite delicious when eaten alive (Osmaston 1951). Most are consumed casually, while prepared ones are stored or sold in seasonal markets. *Pseudacanthotermes spiniger* Sjöst., the most popular food termite in western Tanzania, may be more than one third protein and almost half is a fat used for the frying of chicken. Mature queen termites, raw or roasted, are considered delicacies in many parts of the tropics (Harris 1940a, 1971). The value attached to termites in parts of East Africa is reflected in the fact that specific termite mounds may be personally owned and are protected as valued property (Osmaston 1951; Anon 1995).

Termites are usually captured at their mounds, or while swarming. Mature queens and soldiers can only be obtained by breaking into termitaria, a laborious procedure yielding limited but relished returns. On the other hand, winged reproductives (“kumbikumbi”) can often be collected in huge numbers, when the early rains trigger their emergence. At that time, termites like *Pseudacanthotermes* spp. are handpicked or trapped with a frame of branches built over the mounds, containing a gourd or bowl filled with water. Hatches may even be triggered, by the sprinkling of the mounds with water, or beating logs, playing drums and such to imitate rain (Osmaston 1951; Harris 1971). *Macrotermes subhyalinus* Rambur and related species emerge at night and are attracted to lights, where they can be easily collected in quantity (Figure 6-12).

The Ganda and Heia loved roasted termites and grasshoppers and traded in them (Weiss 1910). The Tindiga and Issansu also considered termites a delicacy, roasting them in the termites’ own fat, salting them slightly, and using them as snacks. Oddly, these tribes shunned the queen, as she “spoils the appetite with her ugliness” (Kohl-Larsen 1943). The Maasai and Tatoga don’t eat termite queens either, while their

neighbors, the Hadza hunter/gatherers, surprisingly appear to not eat insects at all (D Peterson, pers. comm.) At Kilimanjaro, fried termites (“ngumbi”) remain a popular food among the Chagga, especially the children (Hemp 2001a). In other areas, members of termite clans may be forbidden to consume certain termites (Silow 1983).

2.3.3. Lepidoptera

Many caterpillars are regarded as edible in most of southern and central Africa and also in southern and western Tanzania (Silow 1976; DeFoliart 1989). About 30% of edible insect species in Africa are Lepidoptera (Huis 2003). Compared to meat or fish, caterpillars have higher fat and protein contents and correspondingly higher caloric value. Their crude protein and fat contents average about 64% and 16%, respectively, translating to an energy value of about 460 kcal/100 g of dry matter (Malaisse 1997). They also tend to be rich in essential minerals (phosphorus and iron) and also vitamins. Caterpillars were major trade items in pre-colonial Africa, and even today certain types are regionally or locally very popular (Silow 1976; Malaisse 1997; Mbata et al. 2002; Huis 2003). In Central Africa, the market for caterpillars is both lucrative and growing (Malaisse 1997; Mbata and Chidumayo 2003; Balinga et al. 2004). Cultural factors determine, whether caterpillars are acceptable as food or not, with the edible kinds presumably selected by ancestors long ago. Often, sharp differences of opinion on this point are observed, however, even among neighboring peoples.

The advanced instar caterpillars or pupae of certain tree-defoliating moths are considered delicious and are, as a result, popular food items in different parts of Africa (Harris 1940a; Silow 1976; Mbata and Chidumayo 2003; Latham 2003). This is particularly true for the emperor moths (Saturniidae), many of which have common, large and gregarious caterpillars. The pallid emperor, *Cirina forda* Westw., is probably the most widely eaten caterpillar in Africa (DeFoliart 1995). Most famous, however, is the mopane worm or anomalous emperor *Gonimbrasia (=Imbrasia; Nudaurelia) belina* (Westw.), the object of a regionally significant commerce in countries south of Tanzania (Holloway et al. 1987; DeFoliart 1989; Menzel and D’Aluisio 1998). Due to rampant forest destruction and severe drought, the habitat for this “keystone species“, this “moth that lays the golden egg” and its “megabuck caterpillars” has been shrinking (Styles and Scholtz 1995). The mopane worm is now in such demand both for subsistence and as a cash crop, that overexploitation will jeopardize future supplies of this precious resource without careful management, including controlled burning of the woodlands where it occurs (Munthali et al., 1992; Styles and Scholtz 1995). In Zaire, farmers are already engaged in seeding saturniid caterpillars on suitable food plants on their land, to harvest a portion of the caterpillars later, while sparing the remainder to sustain wild populations (Latham 2003). At least another eight saturniid species are eaten in southern Africa. They are a rich source of iron, copper, zinc, thiamine and riboflavin and some are also relatively rich in calcium and phosphorus. Certain saturniid species provide more than 100% of the daily requirements of each of these minerals and vitamins in a 100 g portion of

cooked insects (Oliveira et al. 1976). While over 72 species of tree-defoliating emperor moths, including the mopane worm and the pallid emperor, occur in Tanzania, none attains quite the notoriety and commercial significance that the mopane worm enjoys throughout much of its range farther south. Apparently *Bunaea caffraria (=B. alcinoe* Stoll*)* was locally popular and seasonally collected in the Matengo Mts. near Lake Nyasa (Harris 1940a), while another species (Plate 57) is still consumed in southern Tanzania (P Latham, pers. comm.).

In several parts of Tanzania, Zambia and Zaire, the savory caterpillars and pupae of the bagnest moths *Anaphe reticulata* and *A. panda* (Thaumetopoeidae) are eaten fresh, boiled or roasted, and are dried or powdered for storage (Huis 1996). The larvae of this gregarious defoliator of *Bridelia micrantha* and other trees live in a large communal nest made of strong, yellow silk (Figure 9-1). These nests are usually collected when they contain advanced instars or cocoons and are held as a fresh store for consumption days or weeks later (Fromholz 1883; Harris 1940a; Silow 1976). Related *Anaphe* spp. are also eaten in Nigeria and in Zaire, a pilot project in the latter attempting to ranch *A. panda (=infracta*) for the commercial production of gourmet caterpillars (Munyuli bin Mushambanyi 2000). Twelve pairs of these moths supposedly yield over 9 kg of caterpillars, which command higher prices than other comparable sources of protein. The nutritional value of caterpillars of *A. venata* is claimed to be similar to that of chicken eggs (Ashiru 1988). The caterpillars also contain more crude protein than lamb or pork, and of the eight amino acids essential to humans they contain six. However, consumption of these larvae has been implicated as a cause of ataxic syndrome in malnourished individuals in Nigeria (Adamolekun 1993).

Figure 9-1. Opened nest of *Anaphe* sp. (Thaumetopoeidae) on *Bridelia micrantha*, photographed in Bas-Congo, Zaire. These are multipurpose insects with edible caterpillars that also produce a high-quality wild silk and attractive moths valued by collectors. (Reproduced by permission of P. Latham).

In Zambia and Zaire, caterpillars and pupae of certain species of Sphingidae are a popular food eaten fresh (Silow 1976; Latham 2003). Certain other caterpillars (Lasiocampidae, Limacodidae, Noctuidae, Notodontidae, Hesperiidae) must be pre-

pared by having spines and hairs burned, scraped or plucked off, and excrement removed by squeezing (Huis 2003). These caterpillars are never eaten raw, only boiled or roasted for snacks. As a meat course, they are usually served with corn meal mush (ugali) or stewed with vegetables. Most species of caterpillars involved are polyphagous and some develop 2-3 generations per year. They are usually collected in conjunction with seasonal gathering expeditions for other wild foods such as mushrooms, leaves and fruits. Some caterpillars are transferred to specific trees and collected later, either to give them time to grow, bring them closer to home and supervision, or, purportedly, to improve their taste by feeding on certain hosts (Chavanduka 1975; Silow 1976). Caterpillar trees are often claimed and marked for personal possession.

2.3.4. Coleoptera

About 19% of edible insect species in Africa belong to this order (Huis 2003). By and large, beetle grubs do not seem to be as popular in Tanzania (Harris 1940a) as they are in other parts of the tropics (De Foliart 1995; Malaisse 1997). This may simply be a matter of taboos. It may also reflect more attractive alternatives or convenience, because other insects can be obtained in larger numbers, more often or more easily. Most of the edible beetle grubs live hidden in wood or underground and have to be sought by labor-intensive excavation or sounding out.

In various parts of Africa, several large wood-boring grubs (Cerambycidae), such as species of *Stenodontes* (=*Mallodon)* and *Macrotoma*, are relished (Bodenheimer 1951, DeFoliart 1995; Huis 2003). At Kilimanjaro, other large species and common wood borers of coffee (e.g. *Anthores leuconotus* Pasc. and *Chlorophorus carinatus* Aur.), called “ndoko”, are considered tasty by children who eat them raw (Hemp 2001a). In the same area, white grubs (Scarabaeidae) are collected to be fed to chickens. Other scarab larvae of the genus *Platygenia* and *Oryctes* are eaten in various parts of tropical Africa and beyond (Chavanduka 1975; DeFoliart 1995; Malaisse 1997). In Central Africa, larvae of the giant click beetle, *Tetralobus flabellicornis* (Elateridae) are valued as a delicacy (Bodenheimer 1951). At one time, grubs of the tree-boring weevil, *Sipalus aloysii-sabaudiae* Cam. (Curculionidae), were collected in abundance in abandoned ceara rubber plantations of Tanganyika and eaten boiled or roasted (Harris 1940a). In Angola and West Africa, the palm weevil, *Rhynchophorus phoenicis* (F.), is appreciated as a high-energy food rich in zinc, thiamine and riboflavin (Oliveira et al. 1976). Together with winged termites, the larvae of these weevils rank among the richest sources of unsaturated animal fats (DeFoliart 1990).

While most beetles are eaten as larvae, some adult beetles may also be the objects of culinary pursuit. The larger species of metallic woodborers or jewel beetles, *Sternocera* spp. (Buprestidae) (Plate 66), as well as *Eulepida* spp. (Scarabaeidae) are eaten in southern Africa (Bodenheimer 1951; Chavanduka 1975). The lethargic beetles are easily collected on cool mornings by shaking trees.

2.3.5. Hymenoptera

The maggots and pupae of both stinging and stingless honeybees are considered great delicacies in many parts of the world, including Tanzania (Vosseler 1907i; 1920; Harris 1932, 1940a). They are eaten raw, either chewed up with the comb still containing honey, or separated from the comb as an ugali additive. The Nika between Lakes Nyasa and Tanganyika actually preferred the brood to the honey (Seyffert 1930). Kohl-Larsen (1943) reported that the Issansu ate not only termites and grasshoppers, but also "small black wasps", their identity uncertain. Certain ants (Formicidae) are also eaten in various parts of the tropics, including species of *Oecophylla* and *Dorylus.* The Ngindo e.g. consumed roasted and powdered driver ants during times of famine (Silow 1983). In southern and East Africa, the big reproductives of thief ants (*Carebara vidua)* are considered delicacies eaten raw or fried. They are collected as they emerge from below ground during the early rains (Chavanduka 1975; Skaife 1979; Huis 1996).

2.3.6. Hemiptera

Unlike in other parts of the tropics, where certain stink bugs, water bugs, cicadas and scale insects are sought for food (Menzel and D'Aluisio 1998), few Hemiptera are considered edible in Africa. Several species of large cicadas (*Afzeliada, Ioba, Platypleura, Ugada*) and stink bugs (*Encosternum, Nezara and Sphaerocoris)* are eaten in southern Africa (Skaife 1979; Shaxson et al. 1985; Huis 1996; Malaisse 1997; Rice 2000). The Norumedzo community in Zimbabwe even preserved a forest as a community-designed protected area, because of the traditional appreciation for the harurwa bug, *Encosternum delegorguei*, a pentatomid that masses in this forest annually (Makuku 1993). During the dry season, the green stink bug, *Nezara robusta* Dist., also occasionally occurs in huge numbers on *Brachystegia* trees in Malawi and locals often fell the trees to collect the insects (Esbjerg 1976). If not prepared properly, this insect is said to be very poisonous. Detoxification results from triple soaking in warm water, removal of the head to squeeze out poisonous juices and sun-drying of the bugs.

3. BEES (HYMENOPTERA: APIDAE) AND BEEKEEPING (APICULTURE)

Since time immemorial, bees and honey have ranked prominently in the culture of many African communities (Seyffert 1930). Throughout the savanna woodlands of Africa, beekeeping and trees go together. Bees benefit from trees for nesting, nectar, pollen and resins, while many trees, as other plants, require bees for pollination. Bee products, including honey, beeswax and bee caulk (propolis) are non-wood forest products that play, or could play, important roles for local economies from subsistence to commercial scales (Adjare 1990; Kihwele 1989; Bradbear 1990). As a result of the tree-bee connection and economic dimensions in this relationship, it is no coincidence that the Tanzanian Ministry of Natural Resources and Tourism combines "Forestry and Beekeeping" as a joint division, and that apiculture is taught as a

component of the forestry curriculum at Sokoine University of Agriculture in Morogoro. In British Tanganyika, the Beekeeping Division had already been part of the Forest Department (Smith 1957).

Worldwide, there are perhaps 20,000 species of bees, of which about 500 are social bees mostly in the family Apidae. In sub-Saharan Africa, there are over 3,000 species of bees, many being endemic. Most important among the African Apidae are the stinging (*Apis*) and stingless honey bees (*Trigona*). In addition to the regular honey bee at least five species of stingless bees occur in Tanzania (Smith 1952).

3.1. African Stingless Bees

These small bees, also called sweat bees, nest underground, in hollow trees, under branches or in native beehives (Plate 77). Presumably to discourage uninvited guests, especially ants, *Trigona* spp. build sticky, trumpet-shaped funnels at their nest's entrance made of a mix of wax and resin (Smith 1952; Weaving 2000). For the same reason, the entrances are guarded during the day and plugged at night. Inside, the nest is partitioned into brood and storage sections. Local people relish both the honey and brood of *Trigona* and *Meliponula* spp. The honey is thin and slightly sour, but is said to be delightful and of medicinal use. The colonies are a few hundred to several thousand strong (Skaife 1979). Seyffert (1930) mentions *Melipona* bees as being exploited by the Chagga and Maasai, but since *Melipona* are considered inhabitants of tropical America, he must have referred to *Trigona*, *Meliponula* or *Dactylurina* bees.

3.2. Stinging Honey Bees

The genus *Apis* contains 11 species of stinging honey bees. Of these, ten are Asian, including three exploited by man. The true honey bee, *Apis mellifera* L., may have originated in Africa, subsequently spreading to most of the Middle East and into Europe. After being introduced to the Americas, Australia and the Pacific Islands, this is now by far the most economically important bee in the world. It is ubiquitous everywhere except for the polar regions and cold mountain climates above 3,000 m (Bradbear 1990). Given the huge home range of the honey bee, it is not surprising that in Africa alone nine subspecies of *A. mellifera* are distinguished. Collectively, African honey bees are referred to as *A. m. adansonii*, and three of the subspecies, *scutellata*, *monticola* and *litorea*, are important in the Tanzanian highlands, the high mountains or on the coast, respectively (Hepburn and Radloff 1998).

Since both European and African honey bees are vigorous producers and are relatively disease-resistant and adaptable to many kinds of hives, interbreeding between different subspecies has been undertaken for some time to refine desirable characteristics. Missionaries and private entrepreneurs first introduced European bees into German East Africa, and brief experiments were conducted with these bees at Amani, apparently leading to the eventual “africanization” of the German

bees (Vosseler 1907i). Another such attempt, the 1956 introduction of African strains of *A. m. adansonii* into Brazil, unfortunately turned out to be a mixed blessing (Winston 1992). One of the queens introduced was a *scutellata* bee from Tanzania, i.e., from stock known to be unusually defensive, while the others originated from South Africa. Some of the queens, including the Tanzanian one, escaped and mated with the previously introduced European bees, leading to millions of "africanized" bee colonies throughout tropical South and Central America, and since 1990 also in the southern USA. This vigorous feral hybrid proved to be much better adapted to tropical American conditions than its European parent, and it has the potential for excellent yields of honey. On the other hand, it inherited the mobility of its African parent and gained the reputation of being extremely aggressive and dangerous, accounting for the somewhat exaggerated name "killer bee". Africanized bees also seriously disrupted natural pollinator communities and often displaced cavity-nesting birds such as various parrot species. Although the expansion of africanized bees in the Americas initially led to a precipitous drop in local apicultural enterprises, the bee industry rebounded 5-10 years later, after selection and breeding had resulted in more tractable strains of the hybrid bee. Research into the behavior and ecology of africanized bees, an "elegant insect superbly adapted to its tropical lifestyle" (Winston 1992), also significantly contributed to a better understanding of the African parent.

3.3. Castes

Colonies of stinging honey bees consist of 20,000 to 80,000 sterile females (workers), 300 to 800 fertile males (drones), one fertile female (queen), 5,000 eggs and 25,000 to 30,000 larvae (brood) and pupae (sealed brood) (Adjare 1990).

3.3.1. Worker bees

The worker bees make up possibly 98% of a colony. They are about 10% smaller than the European honey bee, but otherwise very similar, with large honey stomachs, pollen baskets (corbiculae) and mouthparts suitable for lapping and chewing, all three being adaptations to allow the efficient gathering of liquid and solid substances for transportation to the colony. The corbiculae are concave, hairy receptacles on the hind tibiae, suitable for the collection of pollen and propolis. Pollen is slightly moistened for transport. The collection of nectar and water is made possible by temporary arrangement of the modified maxillae and labium into a long proboscis. Nectar is regurgitated after a bee has returned to the hive and, with the help of an enzyme and evaporation thickens and matures into honey to become a non-perishable food and source of energy stored in the combs. This maturation process for honey requires from 2 hours to six days, depending on sugar content (Adjare 1990). Workers themselves eat raw honey and pollen. African bees emphasize pollen collection, which as a source of proteins, fats, vitamins and minerals, allows the rearing of larger broods and frequent swarming.

Worker bees are equipped with several glands that facilitate their multiple tasks. Head glands produce royal jelly (=bee milk), thoracic glands produce an enzyme used to ripen honey, four sets of glands near the tip on the underside of the abdomen are the wax factory, and finally the gland associated with the stinger manufactures defensive poison. During different phases of their life, first as “house bees”, then as “field bees”, workers perform a sequence of distinctive tasks, including sanitation of the hive, feeding of the larvae, drones and queen, caring for larvae and queen, construction and provisioning of combs, guarding and ventilation of hives, scouting, collection of pollen, nectar, propolis and water, and defense. They communicate with fellow workers by dance language to indicate the distance, direction and quality of a newly located source of food or a potential nest site.

Workers either recycle old wax or produce new wax to be mixed with saliva, and mold it into honeycombs. They also collect resinous substances called propolis, mostly from trees such as *Landolphia, Brachystegia, Euphorbia,* and use it for the caulking of cracks in the hive, the shaping of the entrance, for waterproofing the nest cavity and for entombing dead intruders. This bee glue is an aromatic, fatty substance ranging from yellow to brown to green-black in color. *Scutellata* bees are prolific users of propolis (Hepburn and Radloff 1998).

3.3.2. Drones

The male bees, called drones, result from sterile eggs. They are larger and sturdier than workers, have large wings and large compound eyes that meet in the middle. They lack the sting, pollen baskets and glands found in workers. Their only task is to inseminate the queen, which is as lethal for the drones, as stinging is for the workers. Both die shortly after using their posterior equipment. Drones do not collect their own food, but are provisioned by the workers. Excess drones are evicted from the hive or killed by workers.

3.3.3. The Queen

The mother of the hive is of similar size, but slimmer than the drones. Her abdomen is more pointed and her proboscis smaller than the workers’. The queen has no pollen baskets and does not produce wax. Although queens have a functional sting, they use it only occasionally to kill rival queens, without perishing themselves in the process. The queen solicits food and care from the workers, and produces 1,500 to 3,000 eggs per day. Despite her relatively short wings, these are used for an orientation flight prior to and later for swarming or migration. When the queen is ready for mating, she leaves the nest in search of a drone congregation area. Her pheromone triggers a swarm or “comet” of 500 to 1,000 drones in hot pursuit downwind from her. Sequential mating with about 8-10 drones takes place during the 30-minute flight, resulting in the queen being supplied with sufficient sperm for her 3-5 year lifespan. Egg-laying starts as early as two days after mating (Smith 1951).

3.3.4. Brood

The immature stages are composed of maggot-like larvae and of pupae. Workers care for and feed the larvae. One to three day-old larvae are exclusively fed bee milk from the glands of 5-15 day old workers (nurse bees), before being graduated to a diet of nectar and honey, water and some bee milk prior to pupation, when cells are capped with wax. Larvae selected from normal worker larvae and fed exclusively bee milk during five days of development become the queen brood and eventually queens.

Total development from egg to adult for queens, workers and drones of most African bees is generally a rapid 16, 21 and 24 days (Adjare 1990), respectively. *Scutellata* workers require only 18 days (Kihwele 1989). While European bees have longer developmental periods, they also have greater life expectancy.

3.4. Bee Dynamics

While European and African subspecies of the honeybee are very similar morphologically, they differ behaviorally in significant ways (Chandler 1976; Kihwele 1989; Adjare 1990; Winston 1992; Hepburn and Radloff 1998). *A. m. adansonii* is generally more aggressive, swarms and migrates more frequently, has queens of higher fecundity, develops faster, forms conglomerates, tends to abscond, and tolerates a greater range of environmental conditions for foraging. Vosseler (1907i) contested the assumption of general aggressiveness of these bees, attributing a “bad mood” to certain circumstances. Absconding is considered a survival strategy, most often triggered when bee colonies are subject to serious disturbance or experience resource shortages and deteriorating nest quality (Hepburn and Radloff 1998). While disturbance absconding can take place any time and results in complete nest abandonment, seasonal migrations in search of new pastures are a somewhat predictable and more orderly form of absconding, leaving behind only the combs. Predation, drought, fire, soaking rain and excessive heat create discomforts or impact bee pasture sufficiently to leave no other choice than a move. Seasonal migrations are also adjustments to maximize resource access. In Tanzania, the majority of *scutellata* colonies migrate annually during the long dry season, and at Kilimanjaro both *monticola* and *scutellata* migrate up or down the slopes in response to depletion of stores and deterioration of bee pasture. In the Usambaras, this migration began in September when lowland bees would move into the mountains, with a reversal in February-March (Vosseler 1907i). In the Tanzanian lowlands, *litorea* bees generally migrate during periods of dearth of pasture and water. Unlike bees in temperate zones, and because of the propensity for frequent swarming of parts of a hive, the vagrant colonies of tropical bees and their honey storage may be small. As a result, they often fuse into polygynous conglomerates that eventually revert to monogamy through elimination of supernumerary queens (Hepburn and Radloff 1998). Absconding, reproductive swarming and seasonal migrations of African bees account for their extraordinary mobility. While being superb adaptations to a challenging environment, they also account for many of the difficulties in attempts to institute modern kinds of apiculture in Africa.

Despite a slight morphological shift, the africanized bee of the Americas remained largely African and thus largely retained behavioral and ecological characteristics of its African ancestor, explaining its extraordinary rate of spread of 300-500 km per year (Winston 1992).

As colonies of tropical bees never quite shut down, yet continue to be dependent on a continual supply of flowers, stored honey and water, the climate greatly shapes their annual cycle, which is characterized by four distinct periods (Adjare 1990). When drought and insufficient bee pasture prior to the honey season result in exhaustion of stores, bees stop rearing broods and supposedly (?) cannibalize it. In these circumstances, colonies either migrate or are extirpated. With rainfall, flowering plants begin to bloom, pollen and nectar sources increase, and colonies grow again. At this time, bee milk production by worker bees may exceed brood needs. As a result, drones are raised and queen cells initiated. The day after the first queen cell is sealed for pupation, the old queen may leave the hive with half of the colony in tow. This reproductive swarming is quite different from absconding and seasonal migration, in that it coincides with favorable periods and resource abundance (Chandler 1976). Nine days after the old queen leaves the colony, a second swarm may accompany the virgin queen on her search for a new home. Several more swarms may follow at daily intervals. Seven to eight after-swarms are not uncommon, and unseasonal rains may even allow an extra swarming period. Probably due to the numerous predators and frequent occurrence of serious fires, African bees tend to not hoard food as massively as European bees do, instead investing in reproduction through frequent swarming (Hepburn and Radloff 1998). Their propensity to hoard does manifest a large degree of variability though. In Kenya for instance, some colonies store honey while others focus on brood-rearing and reproductive swarming, i.e., within one apiary some colonies may produce good yields of honey, while others produce little or nothing in the same season (T Carroll, pers. comm.). During the period of main honey flow, swarming ceases until resources start diminishing again, and under-worked workers prepare for a second swarming period. After nectar sources run dry, the queen reduces and finally stops egg-laying. As old workers die, the colony shrinks. At this time bees become opportunistic honey robbers. As honey runs out, the colony dies out or migrates.

The episodic flowering in the Tanzanian miombo woodlands, driven by the monsoonal rain patterns and species adaptations, accounts for a complicated biphasic seasonal cycle of *scutellata* populations in this part of the country (Smith 1957; Hepburn and Radloff 1998). This cycle is dictated by very few widespread and prolific pollen- and nectar-yielding species of trees, both tied to two major flows of savanna trees, *Brachystegia* and *Julbernardia*. In August, towards the end of the dry season, as *Brachystegia* prepares to bloom, the *scutellata* queen begins egg-laying and brood production is intensified. The onset of reproductive swarming coincides with the first blooms. From November to mid-January, swarming and brood production intensify until the flowering of *Brachystegia* ends. Between mid-January to mid-May flowering

diminishes and so does brood production. A second major flow begins in May to June when *Julbernardia* bloom, attended by swarming, a short brood production period and population growth. Colonies decline by the end of June. Until August, when the new cycle begins, there are virtually no flowers in the miombo.

3.5. Bee Nests

Wild honey bees nest in any kind of cavity, including hollow trees, rock cracks, holes in the ground and even termitaria. Rarely, the combs may be free-hanging, but then they are usually encapsulated in a protective sheath of propolis. In African bees, nest cavities range in capacity from 5-150 liters, averaging 25 liters, which is about half that of European bees. In miombo woodlands, most bark hives have a volume of from 40-48 liters, with a range from 24-60 (Kihwele 1989). The vertically arranged waxen honeycombs have two layers of horizontal, hexagonal cells opening at opposite ends. While vertical comb arrangements are most common in *scutellata* bees, oblique and horizontal ones also occur, however, at the expense of honey production (Kihwele 1989). Neighboring combs are separated by exact “bee space”, a crucial element in hive design (Adjare 1990). The larvae develop in brood cells in the lower part of combs, while honey and nectar are contained in storage cells in the upper part (Adjare 1990). Drone cells are slightly larger than those of workers, while queen cells are distinctive, large, barrel- or pear-shaped, downward-oriented cells constructed on the bottom and side edges of combs. *Scutellata* bees construct few queen cells and new queens may co-exist for a while, with the mother queen confined to the margins of the brood nest. Two queens may swarm together and co-exist for weeks (Hepburn and Radloff 1998).

3.6. Bee Antagonists

African honey bees face a legion of enemies, exacerbating an already challenging physical environment (Vosseler 1920; Smith 1952; Adjare 1990; Hepburn and Radloff 1998; Crane 1999). In aggregate, man and other predators or parasites may account for the aggressive behavior evolved by these bees, and spontaneous absconding simply is a response to excessive pressures from antagonists (Hepburn and Radloff 1998).

3.6.1. Predators

Humans and honey badgers (*Mellivora capensis*), the latter partly depending on honey and bees for food, are undoubtedly the worst enemies of African bees, although baboons have also been reported as beehive raiders. Until a trap was developed, “sangala” ants destroyed entire colonies of introduced European bees (Vosseler 1907i). Many amphibians, reptiles, birds, rodents and mongoose prey on bees opportunistically, but species in four families of birds specialize on them to some degree. Over 50% (about 600 bees per bird daily) of the diet of some bee eaters

(Meropidae) of which there are eight species in Tanzania, consists of bees. Drongos (Dicruridae), swifts (Apodidae) and honey guides (Indicatoridae) also take their toll of bees. In parts of Africa, a particularly intriguing relationship exists between one of the honey guides and mammalian bee predators (Crane 1999). Both sexes of *Indicator indicator* recruit man, baboons or honey badgers to raid bees' nests. To attract attention, they approach a potential cooperator, perch, conspicuously fan their tail and fluff their wings to bare yellow shoulder stripes. Having secured a connection with a conscript, they repeat a seductive "cherr-cherr", incrementally fly ahead, perch, sing and fly some more until a bees' nest some 20-700 m distant has been reached. Sitting quietly, they wait until it is their turn to scavenge bits of comb spilled or intentionally left as a reward by their bee-raiding recruit.

Many insects and spiders hunt bees on an opportunistic basis. More serious and focused, however, are various ants and some wasps, including hornets, bee wolves (*Philanthus),* and bee pirates (*Palarus).* Among beetles representing five families, the most serious is *Aethina tumida* (Nitidulidae), a destructive scavenger of storage combs throughout Africa that was recently introduced into the USA. A number of scarab beetles (Cetoniinae), including *Pachnoda* spp. are also common pests in hives, where they eat pollen and honey (and maggots?) as a supplement to their normal diet of flowers and fruit. Several moths are also noteworthy, none more so than two cosmopolitan pests, the lesser and greater wax moths, *Achroia grisella* and *Galleria mellonella* (Pyralidae), The caterpillars of these moths are notorious destroyers of the wax in honeycombs, often eliminating entire hives as well as damaging the wood in hives. The death skull moth, *Acherontia atropos* (Sphingidae), which occurs throughout Africa, Asia and into Europe, also enters bees' nests to steal nectar and honey with their short, stout proboscis. These large moths supposedly go unharmed by the bees, by making a squeaking sound that mimics the queen and perhaps by chemical mimicry (Hepburn and Radloff 1998). It has also been suggested that the skull pattern on the thorax depicts the face of a honey bee queen, allowing the moths unmolested access to the bee hives. By contrast, Smith (1952) argues against this benign version of compatibility, claiming that the bees demolish the moths. Corpses of hive invaders are frequently found entombed in propolis, although it remains uncertain whether they were killed by the bees, or whether they died of old age.

3.6.2. Parasites and Diseases

Other than the beelouse *Braula*, a wingless fly, very little is known about parasites and diseases of African bees. Vosseler (1907i) reported only predators. European foulbrood disease (EFD) is present in Africa, but is not serious. A *Nosema* disease that is unique to Africa also does not seem to be a major factor. American foul brood disease (AFD) has to date not been reported in Africa (Chandler 1976), but the potentially troublesome parasitic *Varroa* mites were verified in Saudi Arabia in 1987, in Niger in 1991, in South Africa in 1997, and are rumored to have arrived in the Yemen and Sudan in recent years (T Carroll, pers. comm.)

3.7. Bee Tradition in Tanzania

Perhaps more than any other country in Africa, Tanzania has an extensive cultural connection to bees as a source of bee brood and honey for food and for the preparation of drinks (Seyffert 1930; Harris 1932; Ntenga and Mugongo 1991; Crane 1999). Both honey-hunting from wild nests and beekeeping involving simple hives are traditional forms of interactions with bees. While many tribes in this country have used honey for food, this had special nutritional significance for hunting/gathering and pastoral peoples, as it provided the carbohydrates needed to supplement their high protein diet. Among them, the Hadza, Wahi, Sandawe and Kindiga loved honey and were accomplished beekeepers. The Maasai and Dorobo were active honey hunters and their language is rich with bee-related aphorisms. For the Maasai, honey was not only an essential part of the nuptial price (up to 40 pots of honey), but on long expeditions warriors often relied entirely on honey from wild bees for sustenance (Seyffert 1930; Bodenheimer 1951). For these people the procurement of honey was primarily the responsibility of elders, who frequently employed the volunteer services of "pohoroi", the greater honey guide bird. To assure sustainability of honey, the Dorobo are said to have traditionally left about one quarter of the honeycombs in the nests raided (Seyffert 1930).

Beekeeping was traditionally and remains important today for a number of settled agricultural societies in Tanzania, such as the Gorowa, Iraqw and Chagga (Volkens 1897b; Seyffert 1930; Ntenga and Mugongo 1991; Hemp 1999). For instance, Chagga midmives were in part paid honey for their services. Honey was collected only once a year, at the beginning of the rains, the raid supposedly respecting the queen bee and leaving three honeycombs to maintain the colony (Seyffert 1930). "Real" beekeepers, particularly in Tabora, are also credited with having preserved bee swarms as far as possible, although honey hunting in Africa is generally deemed wasteful and destructive (Harris 1932).

Besides honey and brood for food, several tribes used honey to prepare drinks (Seyffert 1930; Harris 1932) such as honey water (Mbulu), honey beer (Barabaig, Maasai, Dorobo, Nymawezi, Seguha and Sandawe), or to sweeten or potentiate local beers or "pombes" (Chagga, Pare and Gogo). The widely distributed kangara beer is based on honey and, in western Tanganyika, is often distilled into "moshi", a spirit so potent that it was reputed to incite homicidal tendencies in addicts (Harris 1932). Arabs in the territory fermented one part of honey with four parts of water to make vinegar (Seyffert 1930).

The most common traditional beehives in Tanzania include logs (preferably *Chlorophora excelsa*, *Hagenia abyssinica*, *Polyscias fulva*, *Euphorbia nyikae*, *Cupressus* and *Cussonia spicata*), hollowed with fire or axe, and, to a lesser extent, bark cylinders and braided baskets sealed with manure or soil (Seyffert 1930; Harris 1932; Crane 1999). To reduce predation and fire damage, and to capture sufficient solar heat, the hives are either suspended in tree crowns (Plates 58 and 59) or laid on

supporting branches as high as possible. In Mbeya region, trees with useful branching habits, such as *Polyscias fulva*, may be planted to support future hives (Latham 2002). Bee tubes are typically 50-200 cm long, about 30-50 cm in diameter, with 2-3 cm thick walls. The open ends are closed off with bark, raffia or round lids with a hole for access. On the coast and in the Usambaras, logs are split, hollowed and tied together for service. Split log hives customary in Babati District are unique in having a harvesting gate (Figure 9-2) in the middle (Ntenga and Mugongo 1991). To attract colonization of the tubes, the Dorobo coat them inside with honey of a stingless bee and the Chagga lace them with ripe bananas or aromatic herbs called "kimumu" (Seyffert 1930). The Gorowa and Iraqw also bait their hives with a strongly scented plant, *Ocimeras suave* (Labiatae) (Ntenga and Mugongo 1991), and the Tongwe plaster the inside of hives with wax (Takeda 1976). The latter are known to use propolis as a glue for various purposes, such as altering the tone quality of their drums. The capacity of traditional bee tubes averages 25 liters, a very close approximation to nests selected by bees in the wild (Hepburn and Radloff 1998). Especially in baobab country, multiple bee tubes may be found in one tree (Figure 9-3), while hives are typically placed singly elsewhere (Harris 1932).

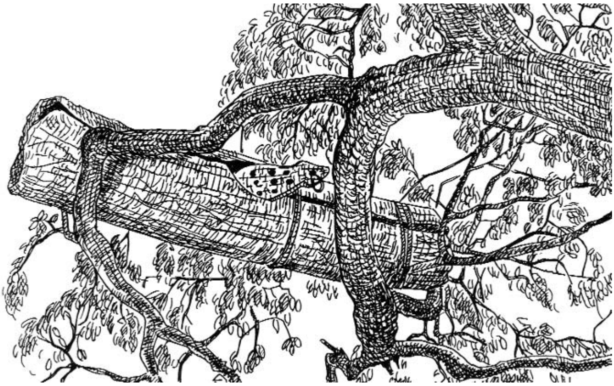


Figure 9-2. A log hive with harvest opening sited in a tree. (From Ntenga and Mugongo 1991; reproduced by permission of Swedish University of Agricultural Sciences).

Figure 9-3. Multiple loghives in baobab, being most visible during the dry season (Mkomazi).

3.8. Beekeeping as an Industry

3.8.1. German Colonial Era

The German colonial government introduced apiculture as an industry, and made relevant research and promotion one of the responsibilities for the resident zoologist at Amani (Vosseler 1907e). Rumor has it, that German ingenuity also engaged local bees for more than honey and wax, using them to turn the tide in an early battle for Tanga at the beginning of World War I (Loveridge 1944). German troops purportedly unleashed the full furor of angry bees on the British troops below, by firing through trees containing nesting bees, resulting in a wildly panicked retreat. On another occasion during that war, the Germans supposedly assembled an ambush using active hives near a narrows where they anticipated the passing of enemy troops (Crane 1999). They wired the hives to an electric battery, and piled up brush to force the soldiers to dismount. While the enemy was busy clearing the obstacles, the batteries were turned on. None of the soldiers or their animals are said to have survived the madly attacking invertebrate army.

Although honey from the territory was considered good enough for export, beeswax was significantly more valuable to the Germans (Vosseler 1907i). Beeswax had had little if any value for indigenous cultures, but by 1905 a total of 1,737,000 kg was exported from GEA, mostly originating from indigenous producers. In that year, wax ranked third in exports, after latex and copra. With over 100 industrial uses, beeswax sold for five times the price of honey and import taxes for wax were one fifth those on honey. This beeswax was considered among the best available, commanding the second highest price on the world market after wax from Brazil and Chile. Among German colonies, GEA actually dominated the export market for beeswax and Germany was the number one wax-importing nation, as it still is today. The significance attached by the Germans to the reputation of high quality beeswax from their territory is reflected in an ordinance dating from 1899, which threatened penalties up to 1,000 rupies and incarceration for adulterating true beeswax with the inferior wax from stingless bees (Vosseler 1920). Apiculture in GEA was judged to have a "great future", as a bee colony rationally treated and cared for had the potential for at least 10-15 kg of honey per year (Vosseler 1907e, i).

3.8.2. British Colonial Era

From the standpoint of apiculture, the British resumed, where the Germans left off, when they took control of the Tanganyika protectorate. The Department of Agriculture initiated extension work to encourage wax production in non-traditional areas, improve wax processing and introduce improved hives such as the Tanganyika beehive for less wasteful beekeeping (Harris 1932). Beeswax remained an important export from Tanganyika, originating from two major beeswax areas, namely from Tabora region up to Lake Victoria and roughly eastward of a line connecting Dodoma and Songea region into what is now the Selous Game Reserve (Harris 1932). In the early 1950s, the Department of Agriculture included "beeswax officer" F. G. Smith,

who later served in the Beekeeping Division as part of the Forest Department. Smith greatly contributed to the understanding of bee botany and the ecology of *scutellata* and *Trigona* bees in Tanganyika (Smith 1951, 1952, 1957).

3.9. Contemporary and Future Beekeeping

In recent years, Tanzania has produced 4,860 tons of honey and 324 tons of beeswax per year, worth 4.9 billion shillings and 648 million shillings, respectively (Anon 2001). As this represents only 3.5% of the estimated potential production, contemporary apiculture appears to be a seriously underappreciated renewable resource. It may also become increasingly endangered, if rampant deforestation is allowed to jeopardize crucial bee pasture. In that case, "no tree-no bee-no honey-no money" may become a painful reality for many rural Tanzanians, who still depend on bees to some extent.

To address these issues, the national government in 1998 approved a National Beekeeping Policy, as a result of which the "National Beekeeping Program 2001-2010" is now in place to be implemented. If successful, it may bring Tanzania closer to making apiculture the major national industry it was before and could be again.

In developing any such programs, it is likely that traditional beekeeping methods that evolved over eons to suit local needs and conditions, will persist. Since German and British days and again during the last decades, development agencies have been involved in numerous attempts to rationalize apiculture (Vosseler 1907i; Harris 1932; Adjare 1990; Ntenga and Mugongo 1991; Hepburn and Radloff 1998; Crane 1999). Most efforts focused on the improvement of hive designs to produce transitional models such as several modifications of the top-bar hives, including Kenyan and Tanzanian versions. Despite honoring Smith's (1952) rule of simplicity, being generally less destructive for bees and in several ways more efficient than traditional log hives, these efforts have not been cost-effective and absorption into local culture has been slow, at best. However, there remain rich opportunities for the improvement of traditional beekeeping by infusing elements of rational apiculture. Routine problems, such as random occupation of hives, migratory habits and absconding of colonies, aggressive behavior, the effects of drought, pesticides, diseases, predation and vandalism among others, will need to be addressed. The economic viability of bee products is likely to only be accomplished by fusing local wisdom with research and organizational improvements, such as cooperatives, extension, training and advances in marketing, transportation and equipment.

Most important under seasonally dry Tanzanian conditions, seems to be an emphasis on maintaining or improving bee pasture, foremost forests. African bees notoriously migrate under drought stress, when access to water and melliferous plants stops (Smith 1957). It may also be possible to achieve greater stability in beekeeping ventures by integrating bees with other land uses. One such system of "apiforestry" was actually in place in German colonial times. The "Zentrale für Honigverwertung H. Herkamp" (Center for Honeyprocessing H. Herkamp) was

apparently the first sizeable commercial apicultural enterprise in German East Africa. This operation combined beekeeping with silk production. The mulberry trees planted not only fed domestic silkworms, but simultaneously yielded a high quality honey (Vosseler 1920). The Germans also encouraged apiculture in conjunction with various other plantation crops, such as coffee, for the mutual benefit of bees and crops (Vosseler 1907e,i, 1920).

In line with this integrated thinking, the combination of apiculture with agroforestry has again been suggested as a means to not only provide supplemental income for farmers, but also to benefit field crops and trees in multi-cropping systems (Kihwele 1979; Pawlick 1989). This will be very fertile territory for research in the future. The main challenge is to identify tree species and crop combinations that prolong the availability of nectar and pollen. Equatorial Africa is particularly rich in melliferous trees (Adjare 1990; Latham 2002), especially Leguminosae, Combretaceae, Malvaceae, Rubiaceae and Moraceae, many of which are multi-purpose trees remarkably well-suited for agroforestry. For instance, by flowering off-season, the native apple ring tree *Faidherbia (=Acacia) albida* could, in certain sites, extend bee pasture into a time when other native trees do not flower, in addition to providing the standard benefits of legume trees (Pawlick 1989). Paradoxically, certain trees that are ill-adapted to a site may be particularly favorable candidates for apiforestry for the simple reason that such trees may experience distress flowering at times when native trees don't bloom. Extension of bee pasture may also be possible by employing other melliferous plants, including herbs, grasses and shrubs. About 8% of the total generic flora of Africa is composed of bee plants (Hepburn and Radloff 1998). At the same time, apiculture sites must be isolated from plants known to produce poor quality or bad honey, such as *Euphorbia nyikae, Brugmansia candida* and sisal (Harris 1932; Smith 1957; P Latham, pers. comm.). *Manihot glaziovii*, grown for latex, was considered an "almost permanent source of honey" which was, unfortunately, bitter and unpalatable (Vosseler 1907i). It was nevertheless considered a good plant with respect to enhancing wax production.

4. WILD SILK MOTHS (SERICULTURE)

Silk is an ancient material produced solely by certain arthropods and valued widely to this day. As the queen of textiles, it has traditionally represented luxury and opulence. Several wild, semi-wild and domesticated species of tree-defoliating Lepidoptera whose caterpillars are equipped with special silk-secreting labial glands have for long been commercially exploited by man to meet the demand for this precious material. The process of rearing any of the silk-producing insects in captivity or collecting their silk in the field for human use is called sericulture.

4.1. Non-African Silk Moths

The mulberry silk moth, *Bombyx mori* (Bombycidae), which is the source of probably over 99% of contemporary silk commerce worldwide, has been domesticated for

almost 5,000 years in China, during which time it's ability to survive in the wild was lost (Schüssler 1937). Trade in this silk and in fine textiles was the lifeblood of the Silk Road, bridging East and West across Central Asia. Although sericulture of *B. mori* eventually spread to various continents, including Africa, Asia still dominates this industry. Worldwide, raw silk production peaked at 105,138 metric tons in 1995 (Raina et al. 2000).

Non-mulberry wild silk moths also continue to play locally or regionally significant economic roles, although at a more modest scale than the domesticated silkworms. Various governments, especially those of India and China, promote their cultivation to this day. Asia's wild silkworm sericulture relies mostly on indigenous, introduced or hybridized species of giant silk moths (Saturniidae), particularly species of *Antherea, Attacus, Rhodina, Samia,* and *Saturnia*. The silks produced by these insects are commercially known as tasar, tussah, fagara, eri, tagore and muga, among other names (Peigler 1993). They often play cultural roles and continue to be in demand as festive textiles for small-scale, eclectic markets. Until not too long ago, some of these silks were also used for leaders in fish lines, strings for musical instruments and as thread to suture wounds (Schüssler 1937). At the same time, some of the giant silk moths provide multiple other benefits, such as in the production of medicine, cosmetics or food, for the propagation of parasitic wasps for biocontrol of forest pests, as showy specimens sought-after by collectors and finally, as objects for experimental research.

4.2. African Silk Moths

African species of wild silk moths occur in four major families: Bombycidae, Saturniidae, Lasiocampidae, and Thaumetopoeidae (Anon 1916; Schüssler 1937). While the cocoons of the bombycids are too small for practical uses and pose other technical difficulties, the other three families include species suitable for commercial silk production.

4.2.1. Saturniidae

Africa has many representatives in this family, but relatively few species are silk producers. They include *Epiphora bauhiniae* Guerin, a defoliator of *Zizyphus* spp., which was traditionally exploited in West Africa for embroideries, but also occurs in East and southern Africa. The African moon or luna moth, *Argema mimosae* Boisduval, a defoliator of *Sclerocarya caffra* from southern Kenya and parts of Zaire to South Africa (Figure 9-4), also has a good, white, shiny, fine silk, but the caterpillars are sensitive to disturbance and moisture (Schultze 1914; Schüssler 1937). The cocoons of this moth have small punctures making them appear like galls with exit holes (Pinhey 1972) and thus, for a bird, not worth probing.

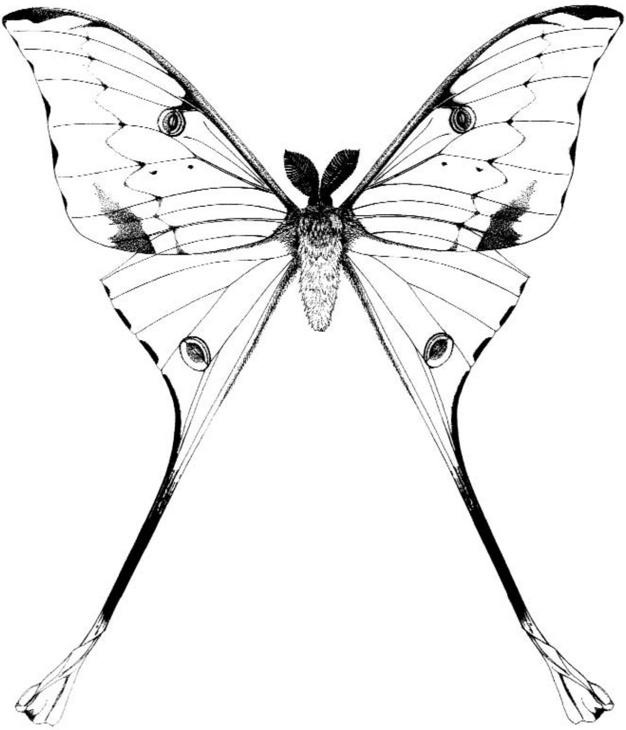


Figure 9-4. The moon moth *Argema mimosae* (Saturniidae) is one of the few African species in this family to produce silken cocoons. (B. Anderson).

4.2.2. Lasiocampidae

There are at least 10 silk-producing species of this family in mainland Africa, including three in East Africa (Ashiru 1989; Schüssler 1937). There are another 10 species of silk-producing lasiocampids in Madagascar, an island that has not only had a significant mulberry silkworm industry since the 1820s (Schultze 1914), but to this day maintains a small, traditional industry producing shrouds from the tough silk of *Borocera cajani* Vinson.

Currently, *Gonometa postica* wlk. and *G. rufobrunnea* Aur., defoliators of mopane trees, are being studied in southern Africa as promising sources of wild silk (Peigler 1993). Their cocoons, traditionally used for ornamental bracelets and ankle rattles (Skaife 1979), yield a silk of commercial quality rivaling that of the domesticated silkworm (Veldtman et al. 2002). Botswana's president is said to boast of a national flag made from this wild silk (Peigler 1993). Another candidate for sericulture, *Gonometa podocarpi* Aur., is as yet better known as an occasionally serious forest defoliator in the East African Highlands.

Little information is available on *Diapalpus congregarius* Strand, a black caterpillar with a yellow dorsal line, which pupates in a communal nest similar to that of processionary moths (Schüssler 1937). In 1914, nests of this insect were sent from Iringa to Prussia's Institute for Textile Industry for evaluation (German Records 1907-14). It is likely that World War I disrupted this attempt to assess another potentially interesting silk producer. This species feeds on *Acacia, Brachystegia, Bridelia micrantha*, cotton, *Ficus* and *Pennisetum purpureum* (Le Pelley 1959).

4.2.3. Thaumetopoeidae

The primary wild silk moths of mainland Africa belong to the bagnest or congregating moths (*Anaphe, Epanaphe* and *Hypsoides*), which are variably classified as members of the processionary moth family (Thaumetopoeidae), the prominents (Notodontidae) or the monkey moths (Eupterotidae). Species of *Epanaphe* occur mostly in Central and western Africa, one species reaching into Uganda, and *Hypsoides* are restricted to Madagascar. *Anaphe* spp. occur through much of sub-Saharan Africa and also in Madagascar.

As many as nine species of *Anaphe* were listed for Africa (Vosseler 1907g; Michel 1911), but to this day much taxonomic confusion remains not only concerning the family affiliation of these moths, but also species designations in the genus. There are probably three valid species of *Anaphe* on the mainland of Africa, while *Anaphe aurea* Butler occurs exclusively on Madagascar (R Peigler, pers. comm.). The banded bagnest moth, *A. panda* Bois., occurs from southern to East Africa, while the reticulate bagnest moth, *Anaphe reticulata* Wlk. *(=A. ambrizia* Butl.), occupies much of the same range, but reaches farther west to Cameroon. *Anaphe infracta* Wals. is often synonymized with *A. panda* or considered a subspecies thereof. It occurs from Guinea into Central Africa and Uganda. The nests of *A. reticulata* are generally smaller and more irregular than those of *A. panda*.

In parts of Africa, including Tanzania, the traditional interest in bagnest moths was apparently restricted to the medicinal use of the silk, i.e., to stop hemorrhaging (African Silk Corporation 1913; Schüssler 1937), to the use of caterpillars for human food (Fromholz 1883; Schultze 1914; Anon 1916; Harris 1940a; Huis 2003) and to the use of nests as pouches to keep gunpowder dry (Latham 2003). Certain food caterpillars, including *Anaphe,* are presently in strong demand in parts of Africa (Munyuli bin Mushambanyi 2000).

The use of anaphe silk seems to have developed in West Africa, where it was used for the manufacture of velvet, plush, and sewing silks (Anon 1916). This product continues to be in demand there for noble garments, but due to overexploitation of the insects, in conjunction with decimation of the natural forests and their main host trees, supplies have dwindled during the past decades (Ashiru 1989). As a result, ceremonial regalia made of anaphe silk are now truly commanding “regal” prices. This may provide a rare trade opportunity for wild silk producers in East Africa. Although *A. panda* and *A. reticulata* feed on many hardwoods (Vosseler 1907g; Gowdey 1912; Anon 1916; Pinhey 1975; Silow 1983; Ashiru 1989), they favor *Bridelia micrantha* (Euphorbiaceae). This small tree is easily cultivated plantation-style and commonly occurs on degraded sites and in secondary woodlands (Morstatt 1910b, 1911d; Michel 1911; Gowdey 1912). Furthermore, experience with sericulture involving *Bridelia* already exists in East Africa.

About a century ago, the German and British colonial governments encouraged the expansion of various standard crops and industries in their colonies, as well as the

exploration and innovative use of hitherto underutilized local resources. One such new industry in Africa was sericulture with domesticated or wild silkworms (Anon 1916). As a result, the Schönheit Bros. started raising mulberry silk moths in Morogoro in the early 1900s (German Records 1907-14). At the same time, the German-American entrepreneur Paul Kueller, in conjunction with the African Silk Corporation, founded in London in 1910 and with a subsidiary in Brussels, Belgium, “discovered” the potential of anaphe silk and very aggressively explored its commercialization in Africa (German Records 1907-14; African Silk Corporation 1913). Anaphe silk resembles mulberry silk more closely than any other kind. Being finer, but of at least equal strength and elasticity, almost without gloss and more easily bleached than mulberry silk, it was rated superior to standard silks for certain industrial applications (Lehmann 1913; Anon 1916; Schüssler 1937).

To gain a competitive edge with his discovery, Kueller conducted highly confidential negotiations with the German colonial government, and succeeded in obtaining an export monopoly for wild silk from the colony and a temporary exemption from export duties. Initially, Kueller had sent local collectors into the bush, paying them 3 rupies per month for delivering “kamjagadja”, as the cocoons were called in Bukoba vernacular. As these turned out to be fairly uncommon in nature (perhaps the hungry collectors preferred to eat them?), he started exploring controlled production on a small plot in Bukoba and later at an expanded experimental plantation of 40 ha of *B. micrantha* at a caterpillar ranch called “Ira” some distance from Bukoba (Vosseler 1907g; German Records 1907-14). As experience with this ranching project was being gained, and to increase wild silk production to economically attractive levels, it was eventually considered advantageous to recruit native collaborators. This scheme envisioned the production of up to 600 kg of nests/ha/year at the caterpillar ranch, to be distributed for stocking in the bush. To control ant predation and parasitic wasps, the developing caterpillar colonies would have to be protected by gauze shelters. The emerging moths would be allowed to escape and fly off a short distance to mate and lay eggs. Eggs and the empty nests would then collected and delivered at the ranch. To further enhance the economic viability of the ranch, diversification with other crops, such as coffee, was contemplated. By the beginning of World War I, this interesting wild silk ranching project unfortunately had not progressed beyond the exploratory stage. Nevertheless, together with experiences in the British colonies (Anon 1916), it provided important insight into potential problems and solutions concerning the biology of the insects, the management of the food plant, and the integration of silk production with other crops and local participants. Even at this experimental stage in 1913, about 5,000 kg of wild silk was exported from German East Africa, about 60,000 kg from Uganda, and about 30,000 kg from Nigeria (Schultze 1914).

In subsequent decades, there were a number of attempts to revive sericulture in Africa, including Nigeria in the 1930s and Uganda in the 1940s, 1970s and again in the 1980s (Ashiru 1989). The latest initiative, starting in the 1990s (Raina et al. 2000), will perhaps put enough science into the exploration of African sericulture to

make it a durable enterprise or at least render a solid verdict on the feasibility of ranching domesticated and/or wild silk moths on this continent. Positive results would certainly please Kueller, who firmly believed that Africa was “predestined to become the silk producer of the future” (German Records 1907-14). Integrating the sustainable production of anaphe silk with that of edible *Anaphe* caterpillars has apparently not been explored yet. This might provide a worthwhile system to consider for its potential to diversify business enterprises, in the same way that mulberry silk is already integrated into agroforestry schemes.

In Uganda, *A. panda* was reported to have two overlapping broods (Gowdey 1912). Adults emerge from one brood in September, the other one between December and January, the primary difference being the duration of the pupa stage, 13 vs. 6 weeks, respectively. Each life cycle lasts about a year, 322 days for the September brood and 413 days for the second brood. In the Congo, the life cycle of *A. infracta* is reported to take only 140 days (Munyuli Bin Mushambanyi 2000).

Eggs of *A. panda* are laid in clusters of up to 300 on the underside of leaves, protected by urticating golden-brown setae from the female’s abdomen. The caterpillars hatch after about 45 days (Gowdey 1912). They shun sunlight and feed gregariously at night on all except very old leaves. Caterpillars of the first brood occur from February to June, while those in the second brood live from October to January (Schüssler 1937). During the day, early instars rest in groups on the bark of host trees and in the evening leave in characteristic head-to-tail procession. As they go, they spin threads of silk that will later guide them back. The last instar larvae of *Anaphe* spp. (Figure 9-1) are 33-40 mm long, brownish-red to yellow-white hairy caterpillars with blackish spiracles, that build a communal, light yellow to reddish-brown silken nest of variable size, sometimes 30 cm or more in length (Plate 60). These are purse-shaped to elongate and are typically located on a tree trunk near the ground, though sometimes in a higher fork or hidden in a cavity or crack. Caterpillars occupy these nests for a considerable period following construction. In Uganda, the nests appear after the rainy season (Gowdey 1912). In that country, the larva stage lasts 107-150 days. Nests of various species of *Anaphe* contain groups of 10 to almost 1,000 last instar caterpillars and may weigh as much as 6-8 pounds, including the insects. Before the first rain, each caterpillar builds an individual, grey-white cocoon inside the nest, for pupation lasting 45-92 days.

The moths hatch through one or two conical projections of the nest. They emerge late in the afternoon and fly at night. They are an attractive white with brown lines on the front wings (Figure 9-5; Plate 61), and have a wingspread of about 50 mm. In *A. reticulata*, the brown network in the front wing reaches the base, while it does not in *A. panda* (Pinhey 1975; Skaife 1979). Females of the latter have a thick tuft of hair at the tip of the abdomen. The moths live for 5-6 days.

The ranching of *Anaphe* in Uganda and Bukoba typically involved one-year old *Bridelia* trees grown from cuttings and planted less than 2 m apart to assure shading

for the sunlight-averse caterpillars (Gowdey 1912; African Silk Corporation 1913). The trees were either stocked with egg masses or full nests, ideally at optimal caterpillar densities of about 100 larvae per tree. Completed nests were either left on the host or transferred to insectaries to reduce parasitism. Since larvae do not pupate right away inside the nest and are prone to abscond when disturbed, special care had to be taken at that stage. After removal of the nest, trees were pruned to create flush growth for the next caterpillar crop.

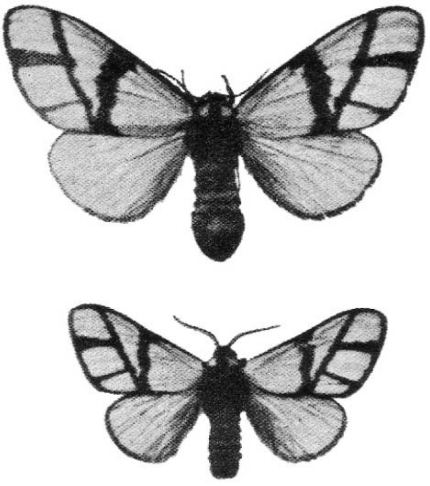


Figure 9-5. Pair of *Anaphe panda* (Thaumetopoeidae), female above. (From Afr Silk Corp 1913).

Unlike some other moths, where silk collection entails the death of the pupae, the nests of *Anaphe* are only collected after departure of the moths, sparing the entire brood, an attractive feature for any ranching scheme. Nests consist of three envelopes of silk (Gowdey 1912). The outer envelope is composed of very fine, but fairly strong and long silk. The second one consists of several closely packed, layered sheets of silk. The innermost envelope is also layered and has the texture of a hard and extremely tough parchment. The silk of this layer is considered the best of the three layers. Although the silk of the individual cocoons inside the nest is very fine, it is often polluted with debris and thus less desirable. After emergence of the moths, the outer envelope of the nest was cut, and the nests were soaked in water for half an hour to disarm the urticating hairs contained in the silk. After removal of the outer coat, the nest was soaked again and the second envelope removed and separated into several layers. Yet another soaking took place each before and after the removal of the third envelope. The silk from different layers was kept separate and pressed and packed for shipment. De-gumming of the silk took place abroad.

Apparently, cultures of *Anaphe* in East Africa remained free of the diseases that tend to plague sericulture with other silk moths in other parts of the world. Several birds and parasitic insects were, however, observed taking their toll. In Uganda, cuckoo, wagtail and especially bulbul preyed on the young caterpillars (Gowdey 1912). In Zambia, woodpeckers were considered worst, followed by various ants, including driver ants (Silow 1976). The parasites and predators include a pentatomid, chalcids, a tachinid (*Tachina onchestus),* as well as the ichneumonid wasp *Cryptus formosus* Brullé (Gowdey 1912; Schultze 1914; Schüssler 1937). Certain pyralid caterpillars living in the nests are considered scavengers.

5. COLLECTIBLES

5. 1. The Collectors

There are basically three reasons why people collect insects, i.e., for subsistence, for professional purposes, or purely as a recreational hobby. Although collecting is occasionally broad-based, it is most often focused on specific groups of insects sought for their utilitarian, scientific, ornamental or other benefits.

5.1.1. Subsistence

In the not too distant past, human survival relied on the hunting of game animals, small and large, as well as the gathering of vegetable foodstuffs and other materials for immediate use or storage. As previously discussed, some traditional cultures in Africa and elsewhere to this day depend on hunting/gathering to some extent, including the collecting of insects and their products for food, medicinal purposes, as a source of arrow poison, as fish and bird bait and occasionally for ornamentation (anklets, bracelets, jewelry, textiles) (Huis 1996).

5.1.2. Professional

There are two distinct categories of individuals who make a living involving the collecting of insects, most of whom have metamorphosed from the ranks of amateurs.

Professional entomologists study insects for reasons of basic science or for applied purposes, such as pest control or the management of useful insects. They routinely employ insects for educational purposes at schools, universities and museums. Taxonomists tend to specialize on groups of insects where discoveries are still to be made or that need revision due to previous lack of information.

Commercial collectors include individuals and firms who collect or breed insects on behalf of biological supply houses, scientific institutions, curio manufacturers and live insect exhibitors, or who act as middlemen in the trade of live or dead insects and their products. Live insect exhibits (butterfly houses or insect zoos) are a relatively new but dynamic development in the commercialization of insects. This often involves the importation of live tropical insects to educate, entertain or simply to create tropical ambience in botanical gardens, fine restaurants, cafes or boutiques.

5.1.3. Amateur

Insect hobbyists come in three varieties: the aestheticist, the naturalist, and the trophy hunter, with a certain degree of cross-pollination between the archetypes. They often swap specimens they caught themselves and/or purchase preserved or live specimens for their collections or as pets. Most entomological hobbyists are attracted to insects for their ornamental qualities, while some aspire to owning the biggest, most bizarre or rarest specimens available. Some collectors are willing to pay thousands of dollars for certain outstanding specimens. In Japan for instance, where some

long-lived beetles are very popular as pets, one trophy stag beetle sold for $ 20,000 in the mid-1990s.

With the increasing rarity and need for protection of some insects, certain naturalists prefer to collect insects non-consumptively, i.e., by photographing them (Plate 78) or by creating insect-based art. Recent advances in digital technology have made mastery of insect macro-photography much easier, combining the primal thrill and challenge of the hunt with the ability to create enduring collections of permanently preserved, technically superb, artistic and biologically interesting images. Some armchair entomologists also enjoy the beauty and diversity of insects displayed on over 1,700 stamps featuring arthropods, issued by more than 300 countries (Evans and Bellamy 1996). While there are a few Tanzanian stamps featuring spiders, this country has yet to make a significant philatelic acknowledgment of its rich insect heritage.

5.1.4. History of Professional and Amateur Collecting

The Golden Age. The collecting of insects for purposes other than food or various products goes back to the Victorian Age, coinciding with a surge of enthusiasm for scientific inquiry. At that time, the hunt required no licenses, had no bag limits, and frequently promised discovery and adventure. As scientists ran out of new species to hunt, describe and study in Europe's backyards, fields and forests, they increasingly were supplied by or joined the ranks of explorers and adventurers that flooded the tropics and other parts of the less-developed world. Well-heeled aristocrats often turned naturalists or at least funded expeditions, their names immortalized in the scientific names of newly described insects, orchids and other organisms. Eventually, as more and more exotic specimens were displayed in museums at home, segments of the educated public developed an appetite for entomological novelty and especially exotic, decorative items from abroad. This was the beginning of the commercialization of ornamental insects and other natural history objects, a trade mostly fuelled by amateur demand.

While modern society may seem far removed from its hunting/gathering heritage, the hunger of amateur collectors for stamps, coins, shells, tulips, orchids, antiques, books, art or insects etc. indicates otherwise. Beyond a genetic predisposition or instinct to hoard for seasons of unavailability, modern society seems to have an intrinsic need for nature (biophilia) to compensate for the artificial stresses of modern life.

The depth of passion for collecting insects is often traceable to beginnings in childhood. For some, collecting may be a passing absorption, while for others it becomes, in the words of Tonnancour (2002), a "terrible compulsion". The thrill of capturing a rare, beautiful and elusive insect for the first time and the life-long memory of this event, are cherished pleasures for the collector, assuring "unimaginable delights", "moments of enchantment" or an "effortless avenue to rapture", as expressed by Hermann Hesse (2002). Many insect collectors are hunters at heart, for

whom to have hunted means to have taken possession. The English naturalist Alfred Russell Wallace, upon catching the spectacular, then undiscovered *Ornithoptera croesus* on Bacan Island in Indonesia, related that he felt closer to fainting than if he had feared certain death and that he had a headache for the rest of the day, so great was the excitement produced by what would "seem to most people as an inadequate cause". Indeed, people growing up in the tropical world may find it difficult to identify with such an emotional response to what to them may be an inconsequential insect. For instance, the Chagga people of Tanzania have only five names for the Lepidoptera, including one that roughly lumps the big and showy ones, i.e., those considered unimportant to daily life (Hemp 2001a). Collectors are particularly passionate about having full sets of certain taxa. Missing species or specimens will plague them for years, their torments transformed into glorious joys when they finally manage to acquire the elusive prize, ideally in the wild.

Modern Renaissance. Although the first wave of entomo-mania eventually subsided, there always remained a core of dedicated aficionados who pursued their insect-based hobbies or professional interests with fervor. Then, about 25 years or so ago, a revival in the demand for collectible insects and other natural history objects began to surface. This may in part be attributable to affluence in the Western World that afforded so many the luxury of travel, which in turn brought exposure to the marvels of the tropical world and fueled a taste for the refined and exotic. Publicity triggered by rainforest destruction and the concurrent loss of biodiversity, combined with sudden realization that biological treasures are no longer guaranteed, but like water and air and soil, may be threatened and precious resources, were certainly contributors to this new gold rush. However, this time around, there are rules and limits concerning the collecting of once free-for-all resources.

This second wave of collecting may actually be a good thing, as it publicizes and glorifies the "good" insects and justifies managed collecting that hopefully provides incentives for the owners of such resources to protect insects and their increasingly threatened habitats. Also, many collectors, initially intrigued by the beauty or natural history of insects or the thrill of capture, eventually become self-trained para-entomologists and, as authorities for certain taxa of insects, often make significant scientific contributions. All serious collectors are likely to become strong advocates for insect conservation.

5.2. The Collected

Given the fact that the more conspicuous species of insects tend to be well known and documented, contemporary scientific collectors are often focused on obscure taxonomic groups of small but species-rich groups that may be useful as bioindicators and thus allow rapid assessments of environmental quality. Amateur collectors, however, still seek specimens that are large or beautiful in terms of color, shape, texture or other ways. Specimens that are rare and in mint condition generally command

the highest prices and so do freaks, such as insects that are half female and half male (gynandromorphs) or color variants. The dead stock insect trade alone runs into the tens of millions of dollars annually (Evans and Bellamy 1996).

The humid tropics of South East Asia and South America are generally the most-species rich areas and thus the most significant suppliers of collectible insects in the world. However, as already observed by Gerstaecker (1873), what is now Tanzanian territory has not only many indifferent genera of insects, but also some specifically or largely African representatives, including some of extraordinary size and beauty. As elsewhere in the tropics, the more humid parts and mountains may be the most rewarding areas in terms of collectibles, but the drier woodlands and semi-deserts also yield some remarkable specimens (Moffett 1958).

Amateur collectors everywhere are most strongly attracted to Lepidoptera and Coleoptera, but several other orders include highly sought-after specimens as well. While running the risk of being judgmental and thus non-inclusive, the following briefly touches on what may be the stars among the collectibles of Tanzania.

5.2.1. Lepidoptera

The dramatic metamorphosis from drab pupa to dazzling beauty gliding carefree through sun-dappled glades in search of flowers and nectar, allegorically elevates butterflies and some moths to magical creatures. The passion of collectors for butterflies is only rivaled by that of ornithologists, who, through organizations such as BirdLife have become a major force behind efforts to conserve natural areas of East Africa and elsewhere. Birds and butterflies on tropical islands, remnant forests such as East Africa's lowland evergreen forests (Sholtz 2000), and on isolated mountains such as in the Eastern Arc, are often highly vulnerable to disturbance, and thus may be particularly important index groups for conservation. The larvae of many collectible Lepidoptera depend on trees, while others often require non-woody plants thriving in forests and woodlands.

Butterflies. Africa harbors a butterfly fauna of around 3,800 species (D'Abrera 1980), 50% being forest-restricted (Kielland and Cordeiro 2000). Mostly as a result of Jan Kielland's single-minded passion, the 1,390 species of butterflies in Tanzania (Kielland 1983, 1990; De Jong and Congdon 1993; Congdon and Collins 1998) are presently better known and documented than any other group of insects in this country. For most of his adult life, Kielland, an amateur entomologist turned semi-professional, tirelessly scouted remote parts of Tanzania for butterflies and described 144 new species, mostly from this country. Following his death in a tragic accident in 1995, he was buried on top of Wanzizi hill in western Tanzania, where the lycaenid butterfly, *Alaena kiellandi,* like many other insects named after him, still resides. Kielland (1990) noticed the butterfly and other faunas of West and East Tanzania to be quite different, separated by the Central Plateau acting as an effective barrier.

The blues and coppers *(Lycaenidae),* representing the largest family of afrotropical butterflies and one that is still yielding discoveries, comprise more than one third of African species. These are all fairly small but often brilliantly colored butterflies. One of the finest of the lycaenids of Tanzania may be the fig tree blue *Myrina silenus ficedula* Trimen, but there are other species of *Aphnaeus, Aphniolaus, Argiolaus, Epamera, Hemiolaus, Hypolycaena, Iolaus, Iolaphilus, Philiolaus, Spindasis* that are valued by collectors and nature lovers. Interestingly, the advanced instars of many lycaenids live in ant colonies, offering a sugary substance in return for license to consume ant brood.

The brush-footed butterflies (*Nymphalidae),* with over 600 species in Africa and at least 220 in Tanzania, is the second largest family of butterflies on the continent. As already mentioned in chapter 3, the caterpillars of many nymphalids are tree defoliators, although none is a serious pest. Adults have brush-like, greatly reduced forelegs. They are attracted to fermenting juices, such as ripe fruit and running tree sap (Plate 62), and the males often visit animal dung and carcasses. The caterpillars are commonly armed with branched spines and in *Charaxes* sport horned head capsules. Nymphalids are mostly robust, large butterflies, including many strikingly colorful genera (*Charaxes, Cymothoe, Euxanthe, Euphaedra, Hypolimnas, Junonia, Kallima, Pseudacraea, Salamis* and *Sallya*) common in Tanzania. Quite a number are polymorphic or exhibit pronounced sexual and/or seasonal dimorphism. *Charaxes* spp. are a particularly popular group with collectors.

The swallow- or swordtails (Papilionidae) are represented by two genera (*Graphium* and *Papilio)* in the Afrotropics. With 40 species found in Tanzania, this country harbors almost half of the 83 species of swallowtails found on the continent (Kielland 1990) and most of the species listed for East Africa (Carcasson 1960). This is one of the most popular groups of collectible butterflies worldwide, and four species are presently listed in the IUCN Red Data Book on threatened swallowtail butterflies of the world. The Kilimanjaro swallowtail, *Papilio sjöstedti* Aur., is endemic to Kilimanjaro, Meru, Ngorongoro and the Mbulu Highlands, with the subspecies P. s. *atavus* restricted to Kilimanjaro. Swallowtails are large, elegant butterflies that are attracted to flowers, animal urine (Plate 63) and to their own dead. Not all species have tail-like extensions on the hind wings, despite what might be expected from the family name. The caterpillars' food plants are mostly Annonaceae, Aristolochiaceae, Lauraceae, Rutaceae and Umbelliferae. *P. antimachus* Drury, the largest African butterfly and one of the largest in the world, is mostly distributed in West Africa but reaches into Uganda. One of the largest swallowtails in the Uluguru and Usambara Mts. is the beautiful *P. pelodorus* Butl. (Figure 9-6). *P. dardanus* Brown, a very common, light yellow and black species is interesting in that it has a number of dissimilar, tailless female forms mimicking milkweed butterflies, as do some other species. The dark, yellow and brown *P. nobilis* Rog., is one of the more unusually colored swallowtails.

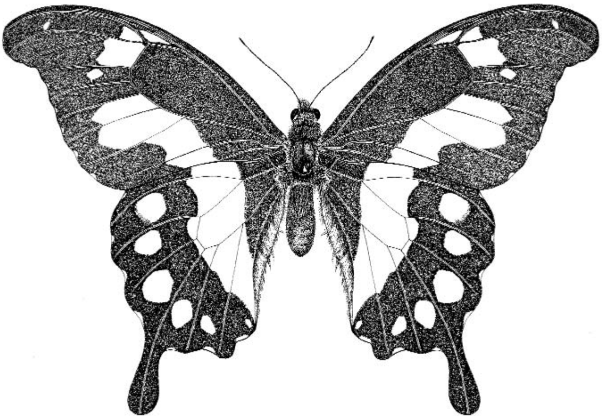


Figure 9-6. Papilio pelodorus (Papilionidae), one of several beautiful swallowtails in montane forests of East Africa. (B. Anderson).

The whites, yellows and sulfurs (Pieridae), are represented in Tanzania with 95 small to medium-sized species. Many, such as *Colotis regina* (Trimen), sport beautifully colored front wingtips. Other attractive species are included in genera such as *Appias, Belenois, Mylothris, Nepheronia* and *Pinacopteryx*. Many pierids are attracted in masses to wet places and have migratory habits. Depending on species, food plants of pierids include herbaceous or woody hosts, most commonly Capparidaceae, Euphorbiaceae, Leguminosae and Loranthaceae.

Other families of butterflies, such as Acraeidae (*Acraea, Bematistes*), Danaidae (*Amauris, Danaus*) and Hesperiidae (*Abantis, Coeliades)* also include splendid specimens. Except for the Hesperiidae, a family of 239 species in Tanzania, the larvae in these families generally do not feed on trees, however.

Moths. While the majority of moths are drab-colored insects, several groups in Tanzania are colorful and highly regarded by collectors. Pinhey (1975) provides numerous illustrations, including host and distributional records for the moths of South Africa, many shared by Tanzania.

The emperor, moon, apollo and prince moths (Saturniidae) include spectacular species, based on a combination of size, color, teddy-bear furriness and showy eye or glass spots on the wings. As a result, this family has a sizeable following of enthusiastic collectors. Occurring worldwide, this family is represented with over 100 species in East Africa and at least 72 in Tanzania (Pinhey 1956; Bouyer 1999). The larvae of most species feed on trees. While the moths are generally night fliers readily attracted to light, a few are diurnal. Particularly sought-after are the moon moth *Argema mimosae* (Bsd.) (Figure 9-4) and the frogfoot *Antistathmoptera daltonae* Tams, both with long trailing hind wings. The biggest race of the latter occurs in closed forest near Tanga. Also beautiful are *Athletes semialba* Sonth., the giant emperor, (*Pseud)Imbrasia deyrollei Thoms*., the males of which have wingspreads over 100 mm, the zigzag emperor (*Nudaurelia tyrrhea* (Cr.)) (Plate 64) and many other species in *Lobobunaea* and related genera. At the same time, some smaller relatives, the apollo moths and princes, are equally charming. While the family is often referred to

as giant silk moths, only few of the East African species pupate in cocoons. Some species are popular human food, as discussed earlier in this chapter.

The Brahmaeidae, a small family of relatively uncommon moths, includes eight afrotropical species in the genus *Dactyloceras*, among them *D. widenmanni* Karsch. in Tanzania. In some respects, these large, mostly brown and cream-colored moths with eyespots, resemble saturniids. Their characteristic wavy, asymmetrical wing patterns, a trademark, give them an irresistible artistic appeal (Plate 65).

The hawk moths (Sphingidae) are another family of moths popular with collectors, including many fairly large and some colorful species. With wings up to 15 cm across, the arrow hawk, *Lophostethus demolini* (Angas), is the largest Tanzanian representative, while the most strikingly colored, with vivid green forewings and yellow and brown hind wings, is the verdant hawk, *Euchloron megaera* (L.). Another large species, the death's head hawk moth, *Acherontia atropos* (L.), attracts attention for the skull-like pattern on the thorax, its habit of invading beehives, the fact that it produces a true sound, and its symbolism in the movie "Silence of the Lambs". Other attractive hawk moths include *Leptoclanis basalis* (Walk.), the oleander hawk, *Deilephila nerii* L., (Figure 3-23) and the measly hawk, *Platysphinx stigmatica piabilis* (Dist.). Few sphingid caterpillars, called hornworms, are tree defoliators, as already discussed in chapter 3.

Other moth families include showy and/or large specimens. Certain day-flying moths are particularly colorful, such as the iridescent and most resplendent of the moths, *Chrysiridia croesus* (Uranidae), an occasionally abundant species along the coast. Others include the black with blue, orange and crimson tiger moths *Heraclia superba* (Druce) (Agaristidae), several noctuids such as *Nyctipao walkeri* with wing-spreads over 12 cm and the striking *Miniodes discolor,* a fine notodontid (*Amyops ingens),* the wild silk moths, *Anaphe* spp. (Thaumetopoeidae), the wood-boring *Melittia* (Sessidae) with bristly hind legs and *Xyleutes vosseleri* (Cossidae) with almost 18 cm wing spreads. Some large Lasiocampidae, *Gonometa and Pachypasa*, and especially *Catalebeda,* with its enormous hairy woolly bear caterpillars (Figure 9-7), also draw attention.

Figure 9-7. Not only adult Lepidoptera, but their caterpillars as well, such as this giant woolly bear (*Catalebeda?* Lasiocampidae) attract young nature lovers. Morogoro.

5.2.2. Coleoptera

Asked what would be inferred about the work of the Creator from a study of His works, a British scientist supposedly replied with "an inordinate fondness for beetles" (Evans and Bellamy 1996). With over 350,000 identified species in 166 families, it is not surprising that this group should be enormously diverse. Many simply impress with their sulky bulk or belligerent armor of spikes, horns and shovels, while others dazzle with sleek, metallic iridescence. For Beckmann (2001), who celebrates many beetles as "living jewels", there is "no such person as a casual beetle collector". Several families have particularly strong followings worldwide, none more so, however, than the Buprestidae, Cerambycidae and Scarabaeidae. Few of these beetles are ever abundant and they are difficult to breed. As a result they may be vulnerable to excessive collecting.

Buprestidae: Metallic Wood Borers, Jewel Beetles, Flying Jewels. This is a family encompassing about 20,000 species of very small to large beetles (1.5-70 mm long) worldwide. Some are minor forest pests, while many are important in the international insect trade. As their common name implies, their most striking feature is a metallic lustre, often in combination with exuberant coloration. A number of East African genera (*Agelia, Amblysterna, Chrysochroa, Evides, Pseudocastalia, Sternocera, Steraspis*) include striking species, as depicted by Ohmomo and Akiyama (1997), most attractive among them *Steraspis speciosa* Klug, as well as *Evides pubiventris* Thoms. and *E. triangularis* Thoms. *Agelia* spp. are 26 mm long, black beetles with yellow bands, very effectively mimicking *Mylabris* blister beetles in size and coloration.

By combining size (37 mm or so) with iridescent colors or interesting markings, the giant jewel beetles (*Sternocera)*, especially *S. pulchra* Waterhouse, *S. iris* Harold and *S. discedens* Kolbe attract particular attention (Plate 66). Among the 16 valid species of *Sternocera* in Africa (Gussmann and Holm 2004), at least the following occur in semiarid to moist savannas of Tanzania: *S. castanea (*Ol.), *S. discedens* Kolb., *S. hunteri* Wat., *S. hildebrandti* Har., *S. iris* Har., *S. klugei, S. ngorongorensis* H. & G., *S. orissa* Buqu., *S. pulchra* Wat. and *S. tricolor* Kerr. Not surprisingly, some of these beauties have traditionally been used as ornaments in textiles, necklaces, ear pendants and head dresses (Skaife 1979). At special ceremonies, Maasai and Samburu women wear necklaces from the elytra of *S. hildebrandti* Har. (Huis 1996), and in southern Africa the larger species of *Sternocera* are considered food (Bodenheimer 1951; Chavanduka 1975). Unlike many other buprestids, *Sternocera* are much more easily collected, as the adults are clumsy, reluctant-to-fly beetles that aggregate usually on flowers of *Acacia* spp. and *Dicrostachys cinerea*. The large eggs (6 mm) are simply dropped or inserted into the ground and are believed to remain dormant for some time. The densely setose larvae are external root feeders on trees, residing several meters deep underground.

Cerambycidae: Longhorn Beetles or Longicorns. Many species in this extensive family intrigue with size (*Acanthophorus, Macrotoma, Phryneta, Stenodontes),* others are very colorful (*Sternotomis, Tragocephala, Tragiscoschema*), some iridescent

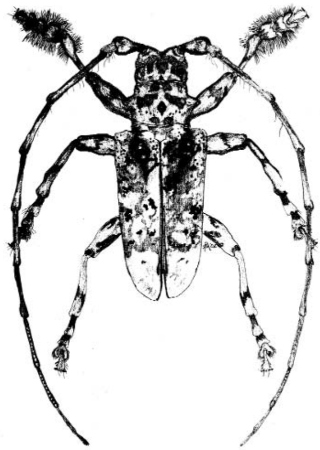


Figure 9-8. Laziopesus sp. (Cerambycidae), which hides very effectively on lichen-crusted bark. (P. Schroud).

(*Philematium*), still others highly camouflaged, and many sport antennae that may exceed the length of their body (Figure 9-8; Plates 67 and 68).

Scarabaeidae: Fruit or Flower Chafers, Rhinoceros Beetles, Dung Beetles. Several subfamilies (Cetoniinae, Dynastinae and Geotrupinae) in this large family include species (Peringuey 1901-02) that are highly priced by collectors for their size, ornamental armor and/or iridescence. Tanzania is blessed with a number of outstanding representatives.

The flower chafers, Cetoniinae, include the goliath beetles, *Goliathus* spp., Africa's largest beetles (50-110 mm) and the heaviest insects in the world. Tanzania hosts three of the five species of *Goliathus*, an all-African genus, including *G. goliatus* Drury. This beetle ranges from Cameroon to Kenya, Tanzania and Uganda, the larvae living in rotten wood of Mimosaceae, Euphorbiaceae and Combretaceae. The slightly smaller *G. orientalis* (50-100 mm long) is known from Zaire and Tanzania, but its larval hosts are unknown. The smallest (40-70 mm long) of the trio, and the scarcest of the five species of goliath beetles, is *G. albosignatus* Boh. This beetle, which intrigues with its simple, noble beauty of velvety black and white patterns (Figure 9-9), occurs in two subspecies from Tanzania southward into northern South Africa. The larval host is unknown. All goliath beetles are attracted to ripe fruit and the sap and gums of *Acacia, Ziziphus, Combretum* and other trees. The beetles congregate at dusk on sleeping trees (often *Sclerocarya birrea caffra*) in woodlands. They fly with the early spring rains when the fresh miombo leaves are brightly colored in pink/pastel/yellow/red, at which time battles between males, whose heads are

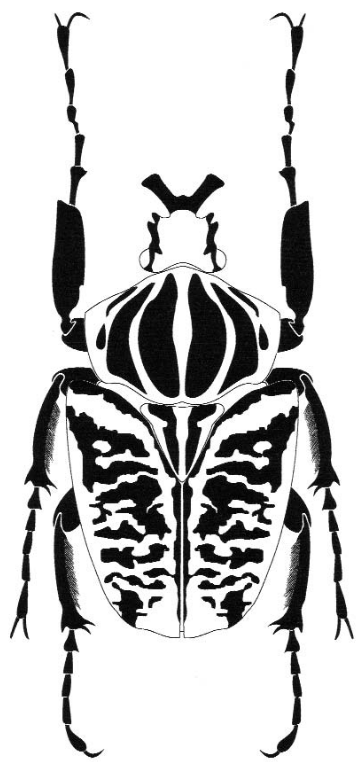


Figure 9-9. Goliathus albosignatus (Scarabaeidae, Cetoniinae), one of three species of goliath beetles occurring in Tanzania. (P. Schroud).

equipped with a forked frontal extension, can be observed. Collectors are willing to pay up to $ 120 for certain "trophy" specimens of large male *G. orientalis preissi* and considerably more for artfully framed specimens. Adult goliath beetles can be kept alive as pets for up to a year and thus artificial culture has been attempted repeatedly. However, raising the beetles in a medium of dead wood and decaying leaves continues to be difficult, even after a first breeding success was reported in Germany in 2000. The larvae, which are up to 150 mm long and weigh over 100 g, take months to develop before pupating in a thin-walled hardened cell made of surrounding materials. In culture, larval mortality tends to be high and females may not lay more than 20 eggs.

Many smaller relatives of goliath beetles, the flower or fruit chafers, are represented in about 3,200 species worldwide, about 70% in the African and Southeast Asian tropics. Many are brilliantly colored and thus are highly popular with collectors (Sakai 1996). Among the stars in this group are *Amaurodes passerinii* Westw., *Argyrophegges kolbei* Kraatz, *Coelorrhina, Conradtia, Dicellachilus, Dicronorrhina, Eudicella, Hypselogenia, Mecynorrhina oberthuri* F., *Neptunides polychrous* J. Thoms., *Ranzania (=Rhamphorrhina) bertolinii* Lucas (Figure 9-10), *Smaragdesthes africana, Stephanocrates dohertyi* Jordan and *St. kiellandi*.

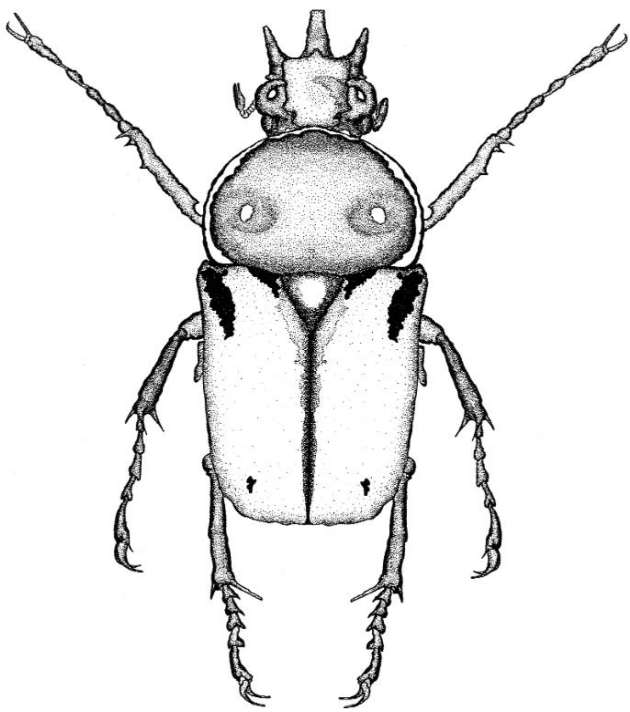


Figure 9-10. A metallic green/silver-grey *Ranzania bertolinii* (Scarabaeidae, Cetoniinae). (P. Schroud).

Many species of rhinoceros beetles (Dynastinae) are large insects with various horns. Although better represented in the Americas and in Asia, there are still 30 African species. In East Africa, *Oryctes* and *Cyphonistes* include the largest representatives, *O. gigas* (Figure 9-11) being particularly rare (Morstatt 1912c).

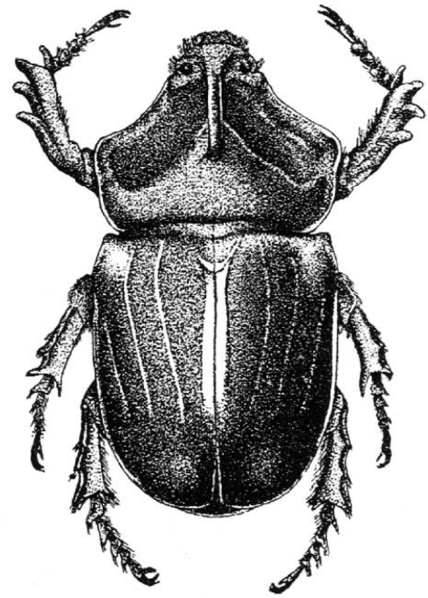


Figure 9-11. Oryctes gigas (Scarabaeidae, Dynastinae), the largest of the East African rhinoceros beetles. (From Morstatt 1912).

Standouts among the dung beetles (Geotrupinae) include *Kheper* spp. and the elephant dung beetle *Heliocopris colossus*.

Chrysomelidae, Curculionidae, Elateridae, Meloidae: These, and some other beetle families, include specimens eagerly sought by collectors for their size, shape, color or other attraction.

5.2.3. Other Orders

Orders other than the Lepidoptera and Coleoptera may not share the huge fan clubs of these two, but nevertheless have their own aficionados. Anything sizable, colorful or having pet potential is likely to be of interest to collectors. Among forest insects such specimens can be found among the Hemiptera, including the giant assassin bugs (*Platymeris*), the leaf-footed mictin bugs (Figure 9-12), artfully designed Picasso bugs *Sphaerocoris* spp. (Plate 69), the bizarre twig snout bugs *Zanna* (=*Pyrops*), and the brilliantly colored rainbow or blue shield bugs *Calidea*. The Orthoptera also include many attractive species suitable as pets, such as the giant

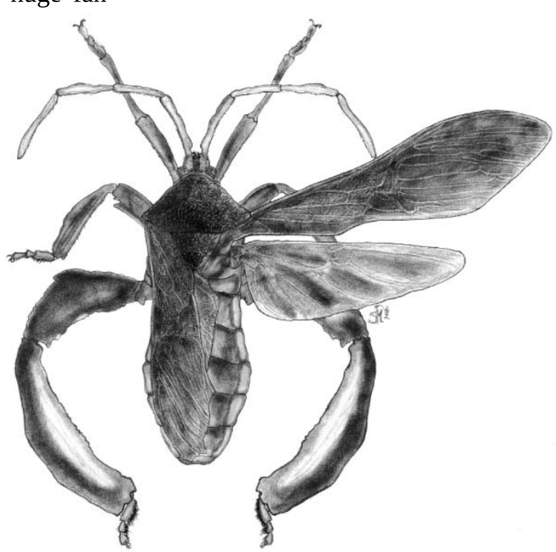


Figure 9-12. A large leaf-footed bug (Coreidae) with unusually conspicuous hind legs. (P. Schroud).

cockroach *Rhyparobia grandis* with wingspreads exceeding 12 cm, the over 20 cm long, winged, walking stick *Palophus* sp., the giant cricket *Brachytrupes membranaceus*, and the curious "inflated" bladder grasshoppers *Physophorina absidata* (Karsch) and *P. miranda* (Peringuey). Certain praying mantids, especially the flower mantid, *Pseudocreobotra wahlbergi* Stål. (Plate 70), *Idolomantis diabolica* Sauss. (=*Idolum diabolicum)* and the dead-leaf mimics *Phyllocrania* spp. (Figure 9-13) also intrigue collectors and naturalists. There are even some Diptera that attract attention, including the larger robber flies, *Hyperechia* spp., and the odd, feather-legged *Lagodias* sp. (Figure 9-14).

Figure 9-13. A well-camouflaged dead-leaf mantid, *Phyllocrania* sp., doing justice to its name. Morogoro.

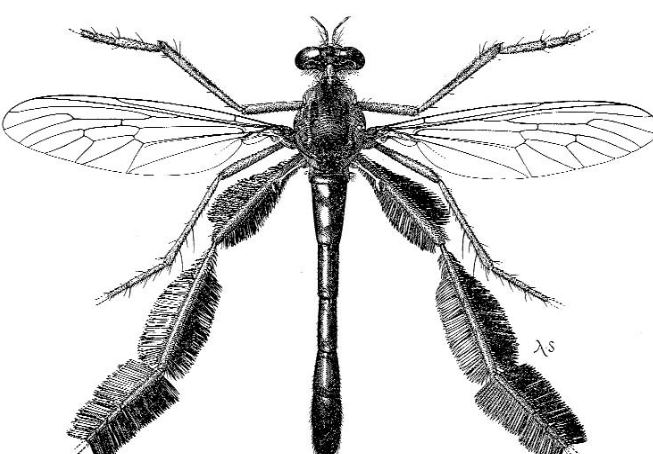


Figure 9-14. A species of feather-legged *Lagodias* (Asilidae), an unusual robber fly. (From: Hull 1962).

5.3. The Producers

Aside from the trade in edible insects and for research and education, there are basically three major kinds of industries and commercial trade in collectible insects (Anon 1983):

A low-value, high-volume industry that involves large numbers of common species of butterflies collected in the wild and processed for use in ornamental objects such as coasters, mats, lampshades, postcards and such. As only the better parts of insects are used, specimens caught need not be perfect. This industry is well developed in Brazil and Honduras, as well as in several Asian and African countries (Plate 71). Since most of the specimens used are iridescent males, this trade is considered sustainable at current levels. Market outlets are generally novelty or tourist curio stores.

High value, low volume industries incorporate insects into expensive, decorative displays such as glass cases, tabletops, domes, wall mounts or jewelry, which assures value-added benefits to the producer country. Brazil and several South East Asian countries engage in this trade that caters to boutiques, interior design businesses and other high-end customers.

Higher value, low-volume industries involve sales of rare, beautiful or unique insects either as live eggs or pupae, or as dead stock to amateur collectors, museums, insect zoos, or students. These insects are either captured in the wild or produced as captive specimens on insect ranches that breed them on native food and nectar plants in near-natural habitats. Specimens are shipped by courier and with legal documents, and arrive at the customer in highest quality condition and accompanied by reliable scientific data. This is typically a community-based or cottage industry that is closely regulated by governmental and scientific authorities, to assure sustainability and greatest benefits to the local producers. Countries like Papua New Guinea, Malaysia and Costa Rica pioneered this approach. Based on their success, insect ranching is now also emulated in countries like Kenya, South Africa and Tanzania. Some biopirates and freelance traders may still operate in black markets and smuggling operations, but neither the authenticity of the species nor other data provided are guaranteed or reliable in these transactions, and penalties for illegal producers, traders and consumers are stiff.

As already discussed, bees, silk worms and edible insects lend themselves well for incorporation into rural development schemes, particularly as they may have historically been components of local culture. Collectible insects may at first appear unlikely candidates for such endeavors, but several insect conservation projects around the world have proven otherwise. These case studies provide important insights for potential producers and thus will be briefly highlighted here.

5.3.1. Butterfly Ranching in Papua New Guinea (PNG)

The ranching for collectibles started in PNG, a country that considers insects a "national resource" and in the constitution specifies insect conservation as a national

objective (Anon 1983). In 1966, seven rare and magnificent birdwing butterflies, *Ornithoptera* spp. (Papilionidae), were declared protected, and a year later the world's largest butterfly, *O. alexandrae* Roth., was proclaimed legally endangered. In 1968, a law banned the taking of any of the seven species of birdwings threatened with extinction. With these steps, PNG tried to stop unscrupulous bio-prospectors who had opportunistically exploited this country's spectacular insect fauna with little if any benefit for the rightful owners of these resources (Anon 1983).

In the meantime, most of the formerly threatened birdwings and other spectacular and sought-after insects of PNG have become available through legal trade. This was made possible by the establishment of several wildlife management areas, the development of butterfly ranching for export as part of the country's rural development program and involvement of an Insect Farming and Trading Agency (IFTA), which has assured quality control and the marketing of insects produced since 1974. Eventually *O. alexandrae*, which has a very restricted range, may be relisted from CITES App. I to App. II.

In order to attract butterflies, insect ranchers culture food plants for the larvae and nectar plants for the adults, often in mix with their home gardens. To assure sustainability of wild stocks, only 75% of the adult insects raised in the butterfly ranches are sold, while the rest are released. In 1995, over 800 villagers in PNG supplied stock to IFTA, whose staff of 20 fills orders from collectors worldwide (especially Japan, Germany and America), while the profits, less 25% for administrative costs, return to the villagers. Specimens are labeled in accordance with scientific protocol and are marketed either as live pupae, preserved adults or as specimens mounted in frames. Presently, a pair of certain species of *Ornithoptera,* such as *O. priamus* and *O. goliath supremus f. titan,* may be worth up to $ 300, but some collectors have paid thousands for outstanding specimens. Serious butterfly ranchers in PNG supposedly earn US $ 2,500-5,000 per year in a country where per capita income is around $ 50 per year (Hanscom 1995). Villages that earn revenue from insects are said to have shown a strong tendency to conserve forests, demonstrating the potential of such enterprises to foster ecologically sensitive economic development.

5.3.2. Butterfly Ranching in Costa Rica

In the late 1970s, encouraged by the success of PNG and spurred by the newly developing ecotourism, Costa Rica pioneered a novel tropical insect industry. This involved the production of live pupae of showy, common butterflies for export to tropical gardens in controlled environments, called butterfly houses or butterfly zoos in developed countries. Such butterfly houses may be set up as mini-zoos for paying guests, or they may operate in conjunction with cafes or shopping malls to create ambience and attract customers. The butterflies are allowed to move freely inside the exhibit, visiting nectar plants and chasing mates. Costa Rica alone recently exported about US $ 1 million worth of live butterflies a year for butterfly houses in Europe

and North America (Gordon and Ayiemba 2003). Other countries followed suit and within a few years, the live butterfly industry morphed into a multi-million dollar global enterprise. About a decade ago, the international butterfly trade was estimated at US $ 100 to 150 million a year (Hanscom and Toone 1995).

At the producer end, this industry typically involves the capture of parental butterfly stock that is brought into greenhouses or screened enclosures containing food and nectar plants for the butterflies (Kulman 1977). To prevent inbreeding, adult males are occasionally caught in the wild and released into the breeding center (Hanscom and Toone 1985). The pupae are collected, carefully packed and rapidly shipped off to distant markets, where the butterflies hatch a few days later in the butterfly houses. Successful butterfly ranches typically combine access to water, availability of food plants, a local source of insects, favorable weather, control of predators and parasites, legal compliance and easy logistics to assure rapid processing and shipping. Larger butterfly ranches in the proximity of tourist centers often supplement butterfly exhibits with gift shops, film rooms, and may organize insect summer camps, where youths attend lectures and participate in field trips, insect rearing and art projects.

5.3.3. Butterfly Ranching in Kenya

There were no large-scale suppliers of live African butterflies for the international exhibit market until the early 1990s, when an integrated rural development project on the Kenya coast incorporated butterfly ranching as one of several promising strategies to protect the Arabuko-Sokoke Forest. Covering 41,600 ha, this forest is the largest single block of coastal forest remaining in East Africa and recognized as a globally important area for biodiversity conservation.

Despite paper protection, this forest was by the early 1990s progressively being degraded by forest-adjacent communities, as well as commercial users supplying urban markets. At that time, fully 96% of local farmers on the periphery of the forest wanted the forest cleared for settlement and farming (Gordon and Ayiemba 2003). To avert this threat, a consortium of international donors, national cooperators and local communities started a planning process, the result of which was a Strategic Forest Management Plan, Kenya’s first integrated forest management plan (ASFMT 2002). The ambitious objective of this plan is to assure by 2027 a fully functioning forest ecosystem at Arabuko-Sokoke without area reduction. The strategies developed focus on forest zonation, ecotourism, environmental education, problem animal management, subsistence use of the forest, biodiversity conservation, commercial use of the forest, infrastructure and human resource development, as well as monitoring and research, with the overriding goal of sustainability of all resources associated with this unique ecosystem.

One specific development component of this strategic plan, a community-based butterfly ranching project called “Kipepeo”, the Swahili word for butterfly, has now

been underway for a number of years. As in Costa Rica, this project involves initial and periodic collecting of wild stock for release in cages and breeding sheds that contain nursery-grown nectar plants for the butterflies and food plants for the caterpillars.

Between 1994 and 2001, cumulative earnings from the export of live pupae from Arabuko-Sokoke exceeded US $ 130,000 (Gordon and Ayiemba 2003). Since 1999, when 55,000 pupae were exported to 11 major customers in the UK, USA and Canada, the Kipepeo Project has been self-sustaining. In 2002, there were 700 butterfly farmers, who derive some 73% of their cash farm product income from the sale of butterflies. Through class visits, videos and publicity for this forest, in conjunction with tourist exhibits in coastal resort towns such as nearby Mombasa and Malindi, there have also been significant educational and promotional benefits and a concomitant increase in ecotourism. Most important, the livelihoods and attitudes of the farmers at Arabuko-Sokoke towards nature conservation seem to have been positively affected, thus arresting the trend towards degradation of this unique forest.

Although the project had overall significant positive impacts for the participants, some problems were experienced, especially with weather, as butterfly populations are depressed at both ends of the moisture spectrum. Increasing competition also threatens to keep the market ceiling low. For the success of this butterfly ranching operation, monitoring of wild populations, rapid access to couriers and minimal paperwork are essential. Synchrony with the annual surge in global demand happened to be reasonably good, although earlier rains would expedite this process. The market extends from March and April to October, and peak production coincides with June to August. Initial research indicated that butterfly ranching, if conducted properly, can be a sustainable operation, as wild populations of the butterfly primarily depend on habitat and the fecundity of these insects tends to be high. It also happens, that in many species it is the more dispensable male that is more colorful and sought-after than are the females.

5.3.4. Butterfly Ranching in Tanzania

Spurred by the apparent success of the Kipepeo Project in Kenya, the Tanzania Forest Conservation Group, an NGO dedicated to the conservation of the high biodiversity forests of Tanzania, recently started another butterfly ranching program, the Amani Butterfly Project (ABP) in the East Usambara Mountains, one component in the Eastern Arc Mountains Forest Conservation and Management Project. At this time, ABP markets pupae of butterflies in four families (Hesperiidae, Nymphalidae, Pieridae and Papilionidae) and several species of day-flying moths (Arctiidae) on behalf of over 300 butterfly farmers in several villages. Live pupae or dried specimens are sent by courier to live butterfly houses and dealers/collectors abroad. Depending on species, a live pupa yields US $ 1-2.50, which may amount to an overall income of about $ 100,000 a year for the project. The profits are divided among farmers (61%), community development (7%), running costs (25%) and the Wildlife

Division (7%). The project involves a host plant nursery and also runs a live exhibit and visitor center for ecotourists (Plates 79, 80).

While butterfly ranching alone cannot be regarded a panacea for community-based conservation, it is certainly an interesting component of integrated strategies for sustainable development of high biodiversity areas, as it promotes awareness for the value of nature, while alleviating some rural poverty.

5.4. Trends in Collectibles

To service the growing community of insect collectors and users, there are numerous professional societies (e.g. African Entomological Society, International Butterfly Breeders Association and African Butterfly Research Institute) and clubs that publish periodicals (e.g. Entomologia Africana), organize fairs and conferences (e.g. Insects in Captivity Conference in 2001), where specimens are traded and purchased, experiences are exchanged, entomological supplies and equipment are available, and new contacts are forged. Whereas, in the past, numerous catalogs advertised specimens and insect collecting accessories, the advent of the Internet has dramatically invigorated the network of collectors by providing direct links between producers of collectibles and consumers. As in the first wave of collecting, there are again numerous superbly illustrated publications in high gloss print that showcase the stars of the insect world. These books are themselves likely destined to become collectibles.

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